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“TENSTAND”
WP2 Final Report: Digital Tensile Software Evaluation

J Lord, M Loveday, M Rides,
I McEnteggart

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January 2005

‘ Computer Controlled Tensile Testing Machines: Validation of European Standard EN 10002-1’

“TENSTAND”

WP2 Final Report:
Digital Tensile Software Evaluation

by

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by Dr M G Gee, Knowledge Leader, Materials Performance Team
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WP2 Final Report
Digital Tensile Software Evaluation

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Executive Summary

This is the final report of Work Package 2 concerned with the validation of Tensile Testing software as part of the EU Project ‘TENSTAND’.

The majority of tensile testing machines are now computer controlled, and the results of the tensile test are usually automatically processed by dedicated software with little or no interaction from the test machine operator. The informative annex A ‘*Recommendations concerning the use of computer controlled tensile testing machines’* in the current issue of EN 10002-1 gives guidance on various aspects of testing associated with computer controlled tensile testing. Until now there has been no co-ordinated systematic evaluation or activity aimed at providing reference data for validating the analysis software used in these tests. Within TENSTAND WP2, work has been carried out to validate tensile test software using a set of ASCII datafiles with agreed values, so that the operators may have confidence in the results produced during testing.

Considerable time and effort was devoted to agreeing the format of the ASCII datafiles and their associated header data, so that commercial tensile software could recognise the data and derive the required tensile parameters. A series of ASCII datafiles were then prepared representing the typical tensile characteristics of a range of industrially important materials – including ferritic and austenitic steels having upper and lower yield strength characteristics and monotonic yielding, and non-ferrous alloys including a number of aluminium alloys and the nickel based alloy, Nimonic 75 (the Room Temperature Tensile Reference Material, CRM 661). Some synthetic datafiles, with different levels of noise, have also been included in the analysis. The datafiles were analysed by a number of different organisations, both industrial and academic, together with testing machine manufacturers using a range of software.

Agreed values for the tensile properties of each datafile were decided by a WP2 working group. Even after careful and detailed inspection of the data and the individual stress-strain curves, some files continued to give problems. It is clear from the results presented that in some cases there is considerable variation and uncertainties in the reported values, which is probably larger than might be expected for the software alone. The main causes of the large uncertainty appear to be related to different interpretations of the definitions in the Standard, and anomalies in the stress-strain curves, often caused by a premature change in the test conditions (speed or control mode). Some of the problems were specific to a particular material behaviour (for instance there were significant problems with some of the files that showed upper and lower yield behaviour), whilst others (such as the large variation in the calculated values for modulus) were a factor in all the datafiles.

Many of these issues are discussed in this report and have formed the basis of recommendations to be put forward to the Standards committee, for inclusion in future revisions of EN 10002-1. A further decision was taken by the WP2 working group to exclude any datafiles where there were issues and anomalies, including all the 5Hz files. **This has resulted in a “Premium Quality ASCII Dataset” of 15 files consisting of at least one file from each of the material types examined. The definitive agreed values for this dataset are given in Section 8.**

These **“Premium Quality ASCII Datafiles**“ are now available, along with the agreed values, for instrument manufacturers and operators to validate their tensile testing software.

CONTENTS

FOREWORD

This Report has been compiled by Jerry Lord & Malcolm Loveday with help from Martin Rides & Ian McEnteggart as part of Work Package 2 of the EU Funded Project ‘TENSTAND’, Contract Number G6RD-2000-00412.

The following partners also made significant contributions, either by undertaking tests, supplying advise and comments, or by participation in the WP2 meetings which were held at Instron, High Wycombe (Dec 2001 and Nov 2002), BSI, Chiswick, London (July 2002), and NPL, Teddington (July 2003):

NAME	ORGANISATION	COUNTRY
J. Aegerter	Hydro Aluminium	Germany
H. Bloching	Zwick	Germany
J.-L. Geoffroy	Sollac / USINOR	France
H. Klingelhoffer	BAM	Germany
R.D. Lohr	Instron	UK
J. D. Lord	NPL	UK
M. S. Loveday	Beta Technology, NPL	UK
I. McEnteggart	Instron	UK
M. Nicholson	ASTM / Instron	USA
M. Pietrzyk	AGH	Poland
M. Rides	NPL	UK
S. Sotheran	Corus	UK

The original work package leader was Prof. Ray Lohr, from Instron, who left the company to take up a new appointment during the course of the project. The leadership was subsequently taken on jointly by Ian McEnteggart (Instron) and Jerry Lord (NPL).

1 INTRODUCTION TO THE TENSTAND PROJECT

The current Standard for the Tensile Testing of Metallic Materials, EN 10002-1, now recognises the dominance of computer controlled testing machines but the systematic technological evidence on which such a Standard should be based has not been readily available. The TENSTAND project (2001-2004), which was funded by the EU under their programme "Promoting Competitive & Sustainable Growth", has sought to address this deficiency by detailed examination of various aspects of the test procedure in the current Standard. The project acronym **'TENSTAND'** was chosen to reflect the focus of the work, dealing with the **Ten**sile **Stand**ard.

The uniaxial tensile test is the primary method used for quality control and certification of virtually all metallic materials. This represents over 80 million tons per annum of various ferrous and non-ferrous alloys sold throughout the European Community with a value in excess of 50,000 million euro. Rapid turnaround of testing is essential to prevent production line delays and automatic testing is now becoming commonplace with robots feeding computer controlled testing machines. Reliable tensile data is also crucial in the design of many safety critical components in power plant, nuclear and aerospace applications where inaccurate data can result in catastrophe.

The importance of achieving reliable and reproducible tensile data from different laboratories and test houses throughout the Community is also vital if fair trade on an equitable basis is to be maintained, otherwise inadequacies in the Standard could be exploited to give unfair commercial advantage to companies interpreting the document in a manner that was not intended by the Standards writing body. Activities in the TENSTAND project have sought to examine these issues via a detailed intercomparison exercise evaluating the effect of different test parameters, a study on modulus, and the generation of reference ASCII datafiles for the validation and calibration of tensile testing analysis software.

The project consisted of a series of targeted research activities carried out within a framework of five Workpackages (WPs), namely:

WP 1: Literature Review A review of relevant literature on tensile test machine control characteristics, modulus determination and inter-comparison exercises, compiling data suitable for the assessment of uncertainty.

WP 2: Evaluation of Digital Tensile Software Specification of software including evaluation of mathematical and graphical methods and preparation of ASCII format tensile data sets of typical engineering alloys. The data sets were used to compare results from the determination of designated material properties including proof stress or upper and lower yield stress, tensile strength, and elongation at fracture using commercial software from the testing machine manufacturers, and in-house university and industrial software.

WP 3: Modulus Measurement Methods Evaluation of algorithms used for determining tensile modulus by software validation using ASCII tensile data sets and by mechanical testing. Findings were also compared with modulus determined using alternative techniques.

WP 4: Evaluation of Machine Control Characteristics This part of the project validated options of test machine control criteria, i.e. new speed changes during the test proposed for inclusion in the Standard. This was achieved by a test programme using a selection of materials, including the Nimonic 75 Tensile Certified Reference Material CRM661, and a range of other industrial relevant materials.

WP 5: Dissemination, Exploitation and Project management Included reviewing interpretations of the existing Standards, EN 10002-1 & EN 10002-5, dissemination of the Project's findings and the preparation of recommendations for a Normative Annex for the Tensile Testing Standard. This WP also included the co-ordination and management of the Project.

The work described in this report deals with the activity in WP2 – the generation and analysis of reference ASCII data sets for the validation of tensile testing analysis software.

Reports from the other work packages are available separately or can be downloaded as pdf files from the TENSTAND website, at www.npl.co.uk/npl/cmmt/projects/tenstand

To avoid repetition throughout the document, EN 10002-1 is sometimes referred to as the "Standard". As the focus of the work is to provide validation of EN 10002-1, it is hoped that the reader accepts that this terminology does in fact refer to EN 10002-1.

2 OBJECTIVES AND ACTIVITIES OF WORK PACKAGE 2 (WP2)

The majority of tensile testing machines are now computer controlled, and in many cases the results of the tensile test are automatically processed by dedicated software with little or no interaction from the test machine operator. The informative Annex A '*Recommendations concerning the use of computer controlled tensile testing machines'* in the current issue of EN 10002-1 gives guidance on various aspects of testing associated with computer controlled tensile testing, but until now there has been no co-ordinated systematic evaluation or activity aimed at providing reference data for validating the analysis software used in these tests. Within TENSTAND WP2, work has been carried out to validate tensile test software using a set of ASCII datafiles with agreed values, so that the operators may have confidence in the results produced during testing. In future, such validation procedures will probably need to become an integral part of the calibration of the testing machine and will also be needed for accreditation purposes. In principle this is a generic problem that will need to be addressed by the majority of testing machines used to determine materials properties, whether it is an impact testing machine, a fracture toughness testing machine, a fatigue machine or a tensile testing machine, as they become increasingly dependent on computers, both for control and processing of results.

In America the ASTM Standards committee E08.03.04 - Data Acquisition Task Group is currently working on producing a draft standard entitled '*Standard Guide for Evaluating Software used to Calculate Mechanical Properties of Materials*' which requires the various sub-committees responsible for individual testing standards to produce ASCII datafiles representing particular tests with agreed values for the designated material properties. A similar concept has already been used within another European funded project where an agreed ASCII datafile was used to compare and hence validate the results associated with the development of the standard concerning Instrumented Charpy Impact Testing (Varma & Loveday, 2002). The same approach has also been adopted in this project, where a series of ASCII datafiles have been prepared representing the typical tensile characteristics of a range of industrially relevant materials. Datafiles were analysed by a number of different organisations, both industrial and academic, together with testing machine manufacturers using a range of software. Results are presented and discussed in the following sections of the report.

It should be appreciated that the use of ASCII datafiles in this manner is not primarily concerned with conventional validation of software in absolute terms via the rigorous analysis of lines of code, but in the pragmatic sense of demonstrating that the underlying algorithms used by the testing machine manufacturers to interpolate or calculate the material properties give comparable answers to those determined by manual analysis of the analogue graphs. The latter activity was carried out by detailed inspection of the files by the WP2 working group.

It is anticipated that a spin-off from this project will be the realisation by the test machine manufacturers of the benefits of incorporating into their new machines the ability to input data in the agreed ASCII format so that in future, it will be a routine process to validate the software either as part of an annual accreditation audit, or more regularly for machines used for product release testing.

The concept behind this approach is shown schematically in Figure 1, which was prepared by Prof. Lohr as part of the TENSTAND project.

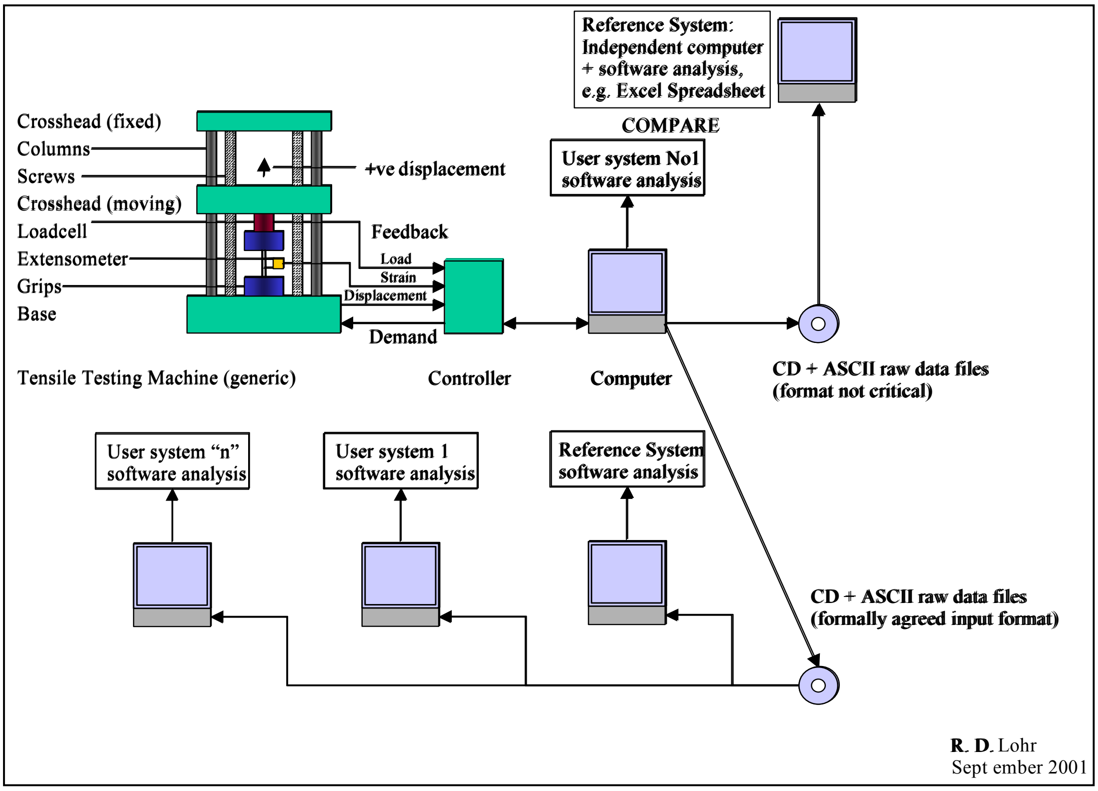


Fig 1 Schematic of machine and software validation and calibration process using the ASCII datafiles and format developed in TENSTAND WP2

It should be noted that considerable time and effort was devoted to agreeing the format of the ASCII datafiles and their associated header data, so that commercial tensile software could recognise the files and derive the required tensile parameters. Datafiles representing typical tensile curves of ferritic and austenitic steels having upper and lower yield strength characteristics and monotonic yielding, and non-ferrous alloys including a number of aluminium alloys and the nickel-based alloy, Nimonic 75 (the room temperature tensile reference material, CRM 661) have been prepared. Some synthetic datafiles, with different levels of noise, have also been included in the intercomparison.

Following a software intercomparison exercise involving 13 organisations, the correct values for the various ASCII files were agreed by manual inspection of the raw datafiles by a working group, rather than accepting a statistical average value determined in the round robin exercise. This is unlike the procedure normally undertaken when determining agreed certified values for reference materials, and can be considered equivalent to identifying and removing "outliers" based on logical, reasoned argument. For some parameters, such as modulus and proof stress, it was not possible to specify a single value for the parameter, and a range of values is given. Uncertainties for each parameter have been calculated and should be included as a "software factor" in any uncertainty budget developed. The ASCII datafiles and the agreed tensile parameters developed in the TENSTAND project are now available for software validation purposes, on the TENSTAND web site.

3 AGREED TENSTAND ASCII FILE FORMAT

A major task within WP2 was the agreement of the ASCII datafile format for the intercomparison exercise and for the future validation of commercial software packages by direct input into the tensile testing machine software. A number of meetings were held to agree the details of the ASCII data format and the rate for data capture. Following a meeting of the main WP2 partners in November 2002 at Instron, High Wycombe, the following format was agreed (Fig 2). Dr Murray Nicholson had also attended the meeting in his capacity of Chairman of two ASTM committees that are considering a similar approach to that adopted in TENSTAND, to ensure that wherever possible, the recommendations from the European project will be identical to the American approach.

Header

```
"Reference";"EN10002-1"
"Identification";"Tenstand"
"Material";"Nimonic"
"Extensometer to crosshead transition";0.00;"mm"
"Specimen geometry";"Circular"
"Cross-sectional area = So"
"Extensometer gauge length = Le"
"Extensometer output in mm"
"Parallel length = Lc"
"Data acquisition rate 50Hz"
"Data row for start force reduction (Hysteresis) = Hs"
"Data row for end force reduction (Hysteresis) = He"
"Data row for switch to crosshead = Cs"
"File length N data rows"
"File width M data columns"
```

Test Parameters

```
"So";78.46129;"mm2"
"Le";50.00000;"mm"
"Lc";60.00000;"mm"
"N";3127
"M";4
"Hs";0
"He";0
"Cs";0
```

Data

```
"time";"crosshead";"extensometer";"force"
"s";"mm";"mm";"kN"
0.00000;0.0515983300;0.0000579191;0.1913788000
```

Fig 2: Agreed format of TENSTAND ASCII datafiles

The agreed format of the datafile contains a header, details of the test parameters and the data. The header includes basic details on the material and definitions of the various parameters; the section on test parameters includes actual values for the specimen geometry and extensometer gauge length and, where appropriate, information on the machine control and crossover conditions, followed by the data from the test in the format of time (s), crosshead displacement (mm), extensometer extension (mm) and force (kN).

The datafiles generated in this project were then used in the software intercomparison exercise described later in the report to evaluate and compare results from different software packages for determining material properties such as modulus, proof stress or upper and lower yield stress values, tensile strength, and elongation at fracture.

4 GENERATION OF REPRESENTATIVE STRESS-STRAIN CURVES

The generation of the datafiles for the intercomparison exercise was carried out by Instron, Zwick and TKS, using materials and specimens supplied by the project partners. In total over 30 tensile tests were performed on 11 batches of material, chosen to represent a range of commercial alloys with different characteristics. A further set of synthetically generated data was later supplied by NPL for inclusion in the exercise. This was an important set of data as it was independent of the machine software used during testing, and it had well-defined, known material parameters. A similar approach is being explored by the ASTM Working Group as mentioned above.

The list of materials is given in Table 1 below, and the full list of files generated within WP2 is given in Table A1 in the Appendix.

Table 1: Materials included in the intercomparison and validation exercise.

Files	Material	**Class and Characteristics**	**Organisation/ Supplier**
1-8	CRM661 Nimonic 75 *	Monotonic yielding	NPL / IRMM
9-12	13% Mn Steel	High work hardening	CORUS
13-16	S355 Structural steel	Upper & lower yield	CORUS
17-20	316L Stainless Steel	Monotonic yielding	CORUS
21-24	Tin coated packaging steel	Stress softening	SOLLAC
25-28	T462 sheet steel	Upper & lower yield	SOLLAC
29-32, 49-52	DX56 galvanised steel *	Low work hardening	TKS
33-36, 53-56	Bake hardened steel sheet *	Upper & lower yield	TKS
37-40	Aluminium AA 5182 (Hard)	Stepped yielding	Norsk Hydro
41-44	Soft Aluminium AA1050	Non-linear	Norsk Hydro
45-48	Aluminium AA 5182 (soft)	Serrated yielding	Norsk Hydro
57-64	Synthetic generated curves	Monotonic yielding	NPL

* Material tested by more than one organisation

The tensile testing was carried out according to the conditions in the current standard, EN10002-1, and the files presented in the format agreed above. Tests were carried out in crosshead control, at the fastest rates permitted, which gave the most demanding situation for the machine control and analysis software, and resulted in a smaller file size. All tests used data sampling at 50 Hz, but an aspect of the exercise was to examine data that had been captured at lower sampling rates. Instead of carrying out an expensive set of repeat tests with a lower data sampling rate (outside that specified in the Standard), a pragmatic approach was taken whereby the original datafiles were re-sampled to reduce the 50 Hz data to an equivalent 5 Hz test.

Following presentation of the stress-strain curves to the TENSTAND project consortium, a subset of datafiles was selected for inclusion in the intercomparison exercise, including at least one 50 Hz and one 5 Hz dataset for each material type. A subset of 34 datafiles was chosen from the original set of 64 (given in Table A1 in Appendix A). This file subset is listed in Table 2 below, and load-extension plots of each batch of material (50 Hz data only) are presented in Figs 3 on the subsequent pages. Actual examples of two of the ASCII datafiles created by Instron and Zwick are included in Table A2 in the Appendix.

Table 2: Subset of 34 ASCII datafiles for the WP2 Software Intercomparison exercise

TENSTAND :WP2: ASCII Data Set Files for Software Inter-Comparison

File No.	Material	Original File Name	Source	Data Capture Rate, Hz	Proof or Yield Stress
1	Nimonic 75, CRM 661	CRM 661-GBX 178-1	BCR/IRMM	50	P
3	Nimonic 75, CRM 661	CRM 661-GBX 178-1	BCR/IRMM	5	P
6	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	BCR/IRMM	50	P
8	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	BCR/IRMM	5	P
10	13%Mn Steel	P1M 23-2	CORUS	50	P
12	13%Mn Steel	P1M 23-2	CORUS	5	P
13	S355 Structural steel	P1M 24-1	CORUS	50	Y
15	S355 Structural steel	P1M 24-1	CORUS	5	Y
17	316L Stainless Steel	S1C 20-1	CORUS	50	P
19	316L Stainless Steel	S1C 20-1	CORUS	5	P
22	Tin Coated packaging steel	SOLLAC F72-No7-2	SOLLAC	50	P
24	Tin Coated packaging steel	SOLLAC F72-No7-2	SOLLAC	5	P
26	Sheet steel	SOLLAC T462 No6-2	SOLLAC	50	Y
28	Sheet steel	SOLLAC T462 No6-2	SOLLAC	5	Y
30	Sheet steel	TKS-DX56 No 2-2	TKS	50	P
32	Sheet steel	TKS-DX56 No 2-2	TKS	5	P
34	Sheet steel	TKS-ZStE-180-No1-2	TKS	50	Y
36	Sheet steel	TKS-ZStE-180-No1-2	TKS	5	Y
38	Aluminium Sheet	VAW-hard AA5182-No3-2	VAW	50	P
40	Aluminium Sheet	VAW-hard AA5182-No3-2	VAW	5	P
42	Aluminium Sheet	VAW-soft AA1050 No 5-2	VAW	50	P
44	Aluminium Sheet	VAW-soft AA1050 No 5-2	VAW	5	P
46	Aluminium Sheet	VAW-soft AA5182 No 4-2	VAW	50	P
48	Aluminium Sheet	VAW-soft AA5182 No 4-2	VAW	5	P
50	Sheet steel	TKS-DX56-L050-B12-5-Probe 2	TKS	50	P
52	Sheet steel	TKS-DX56-L050-B12-5-Probe 2	TKS	5	P
53	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 1	TKS	50	Y
55	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 1	TKS	5	Y
57	Synthetic Digital Curve	NPL Zero Noise	NPL	50	P
58	Synthetic Digital Curve	NPL Zero Noise	NPL	5	P
61	Synthetic Digital Curve	NPL 0.5% Load Noise	NPL	50	P
62	Synthetic Digital Curve	NPL 0.5% Load Noise	NPL	5	P
63	Synthetic Digital Curve	NPL 1% Load Noise	NPL	50	P
64	Synthetic Digital Curve	NPL 1% Load Noise	NPL	5	P

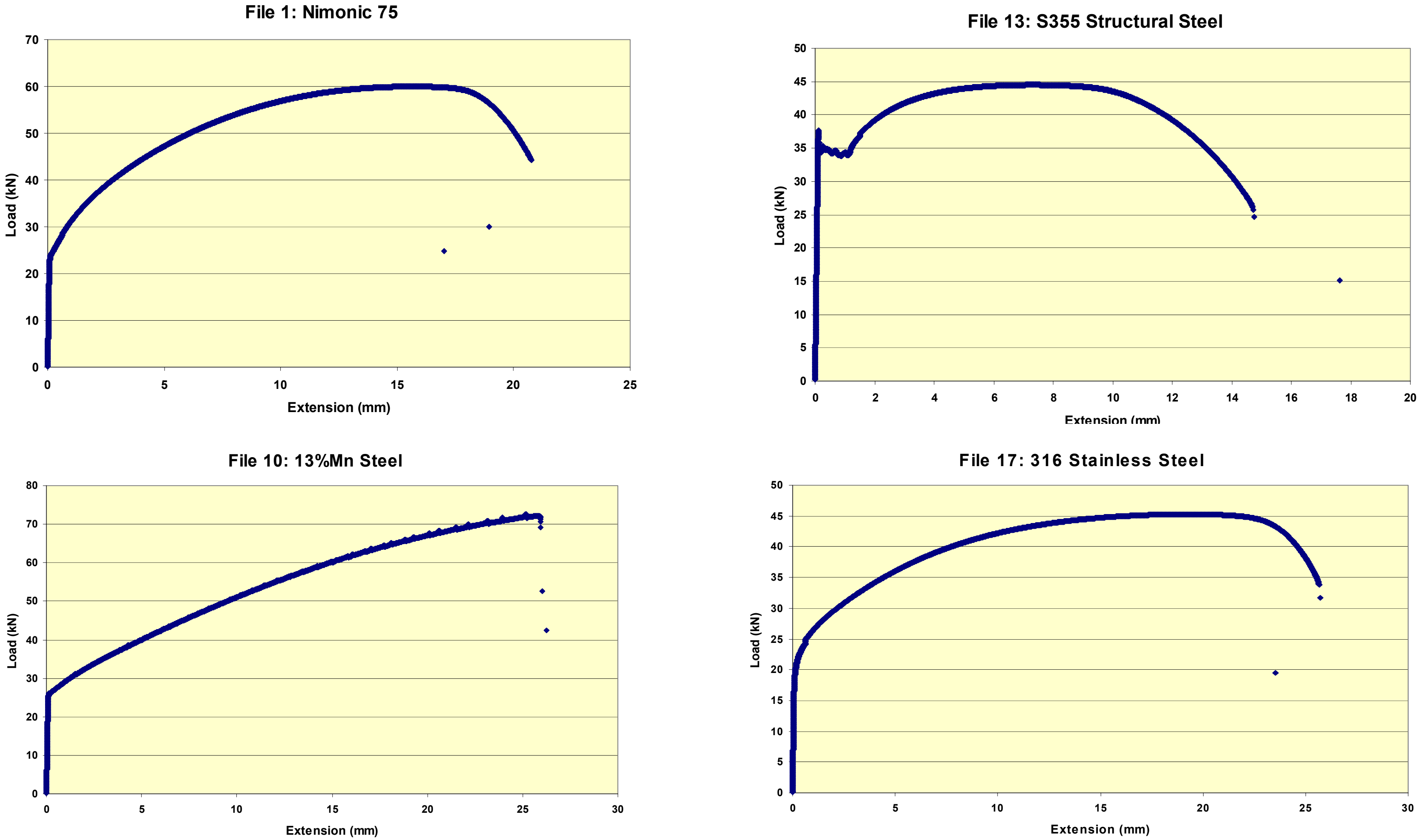


Fig 3: Load-extension curves for each material type

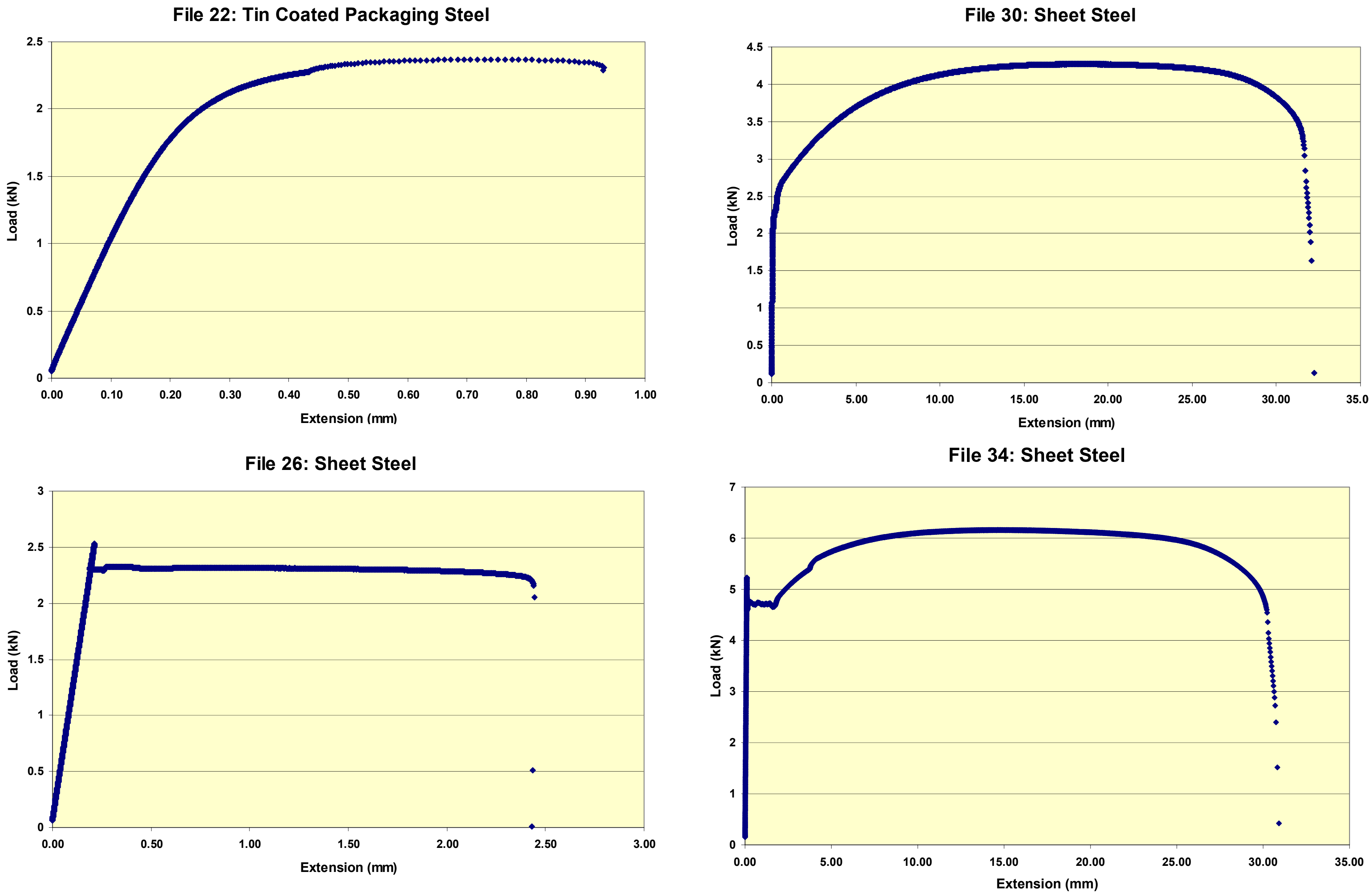
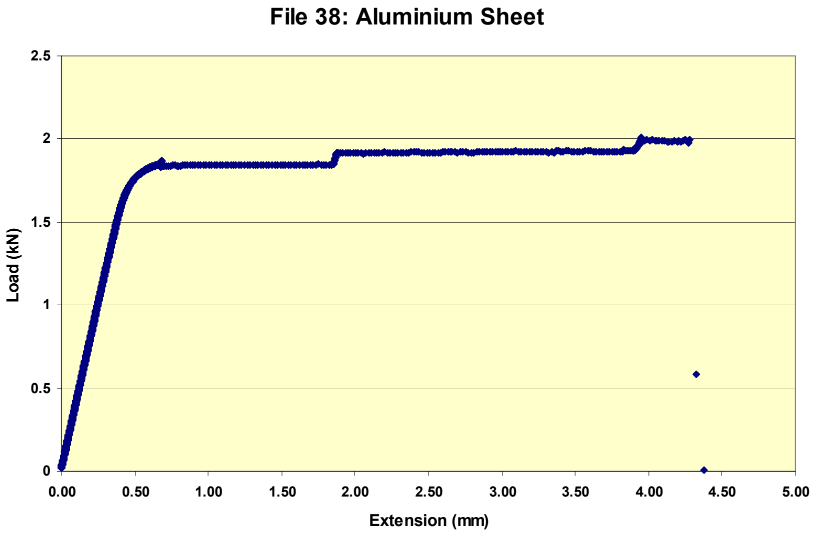
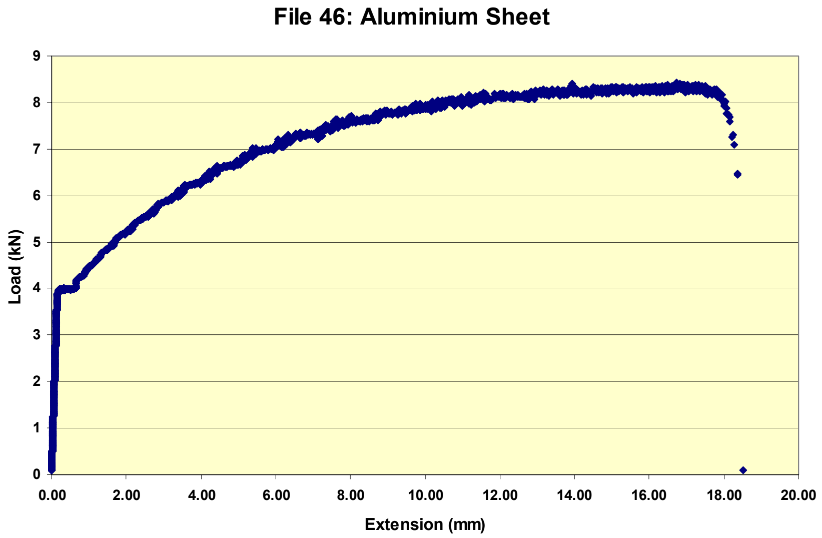
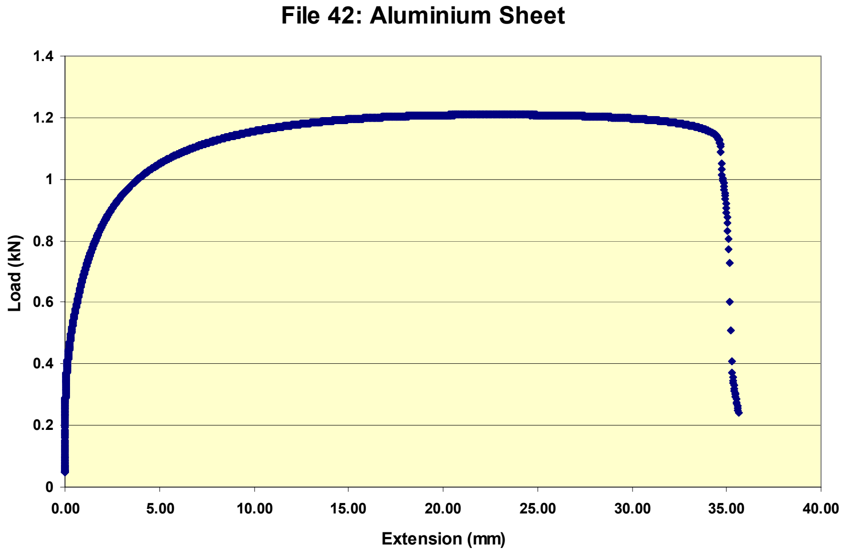


Fig 3 (contd): Load-extension curves for each material type







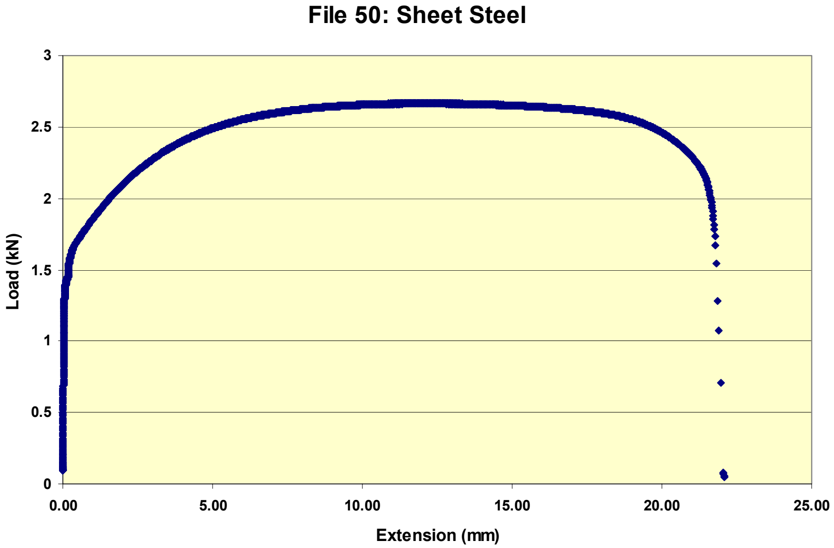
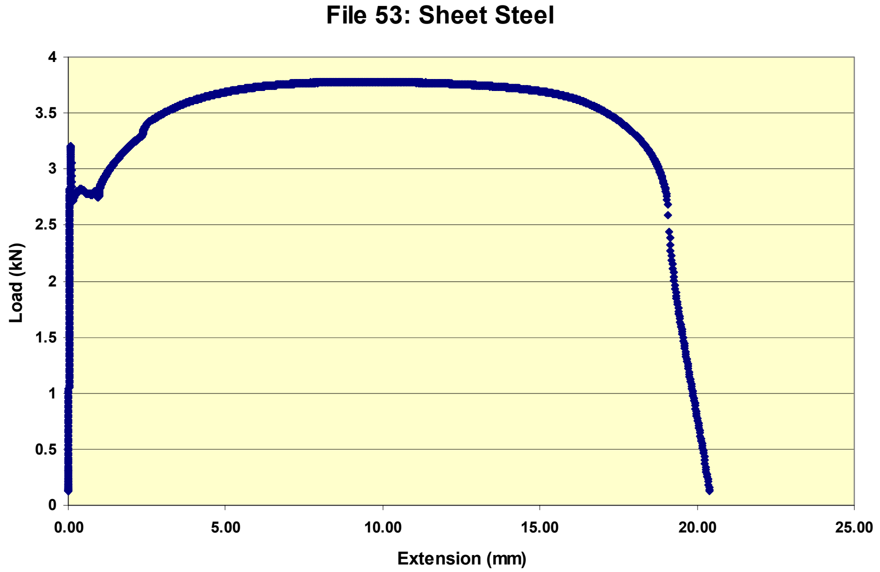
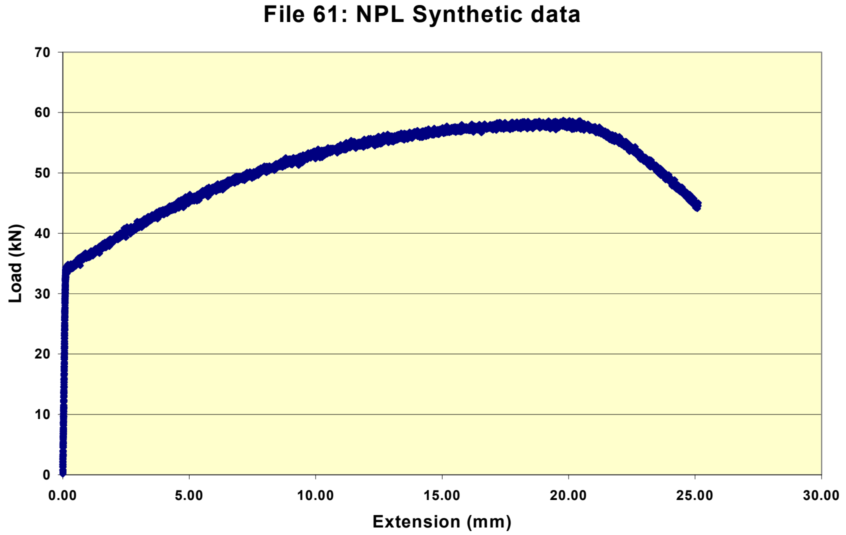
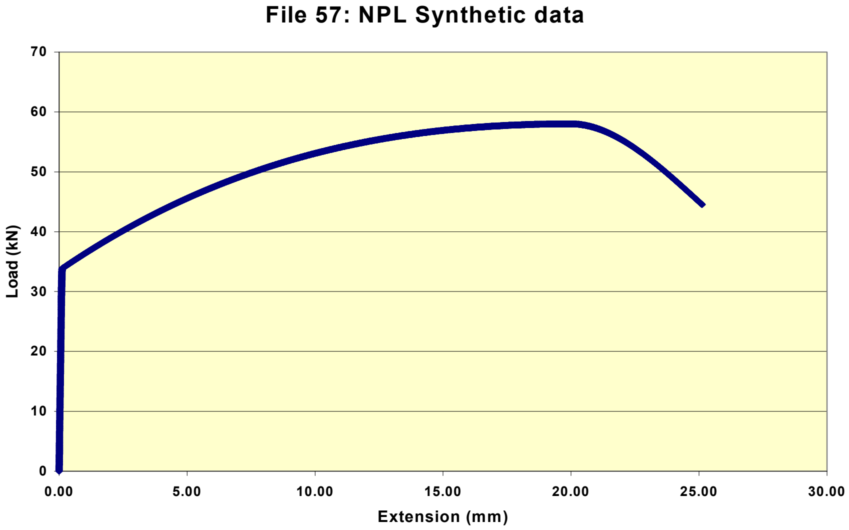


Fig 3 (contd) Load-extension curves for each material type







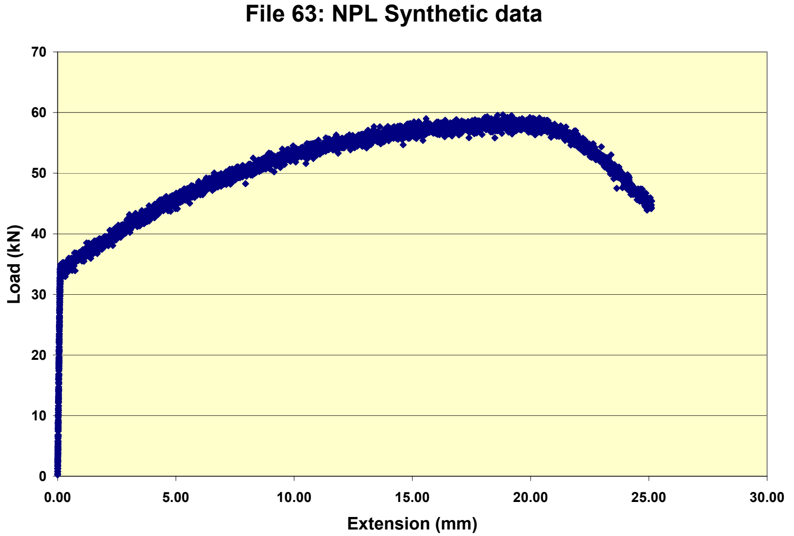


Fig 3 (contd): Load-extension curves for each material type

5 DISTRIBUTION OF FILES AND LIST OF PARTICIPANTS

Following agreement of the TENSTAND partners at the project meeting in Dublin held in February 2003, the datafiles were distributed on CD for analysis. The list of organisations invited to participate in the exercise is given in Table 3.

Table 3: List of participants in WP2 ASCII datafiles analysis

Organisation	Contact	Country
BAM *	Dr Hellmuth Klingelhoffer	Germany
BAOSTEEL	LI Heping	China
CORUS *	Stuart Sotheran	UK
Dirlik Controls	Dr Turan Dirlik	UK
DMG (Dennison-Mayes) *	Dr Darren Burke	UK
EMIC	José Gonçalves	Brazil
ESH Testing Ltd	Trevor Allen, Martin Button	UK
Hounsfield Test Equipment	Edmund Hall	UK
IBMB	Dr.-Ing. Martin Laube	Germany
Instron (Schenk)*	Ian McEnteggart	UK/USA
Lloyd Instruments Ltd	Toby Rogers , Sarah Brien	UK
MTS	Gary Dahlberg	USA
NPL *	Dr Jerry Lord	UK
Norsk Hydro *	Johannes Aegerter	Germany
PLANSEE	Dr Wolfrom Knabl	Austria
Servotest	Nick Richardson	UK
Tinius Olsen Testing Machine Co.	Earl Ruth/ J.A.Millane	USA
Sollac/USINOR *	Jean Luc Geoffroy	France
Zwick (Dartec) *	Herman Bloching	Germany

*** TENSTAND Consortium partners**

In total 13 organisations completed the analysis, using a variety of commercial test machine software, other proprietary software and in-house software. Details of the software packages used are included in Table A3 in the Appendix.

Some participants returned more than one set of results for cases where different software or analysis parameters had been used, resulting in 14 sets of data. As is common practice with such intercomparison exercises, the results have been presented in a form that preserves the anonymity of the organisation, and are labelled 1-14 corresponding to the order in which the results were returned. Of course, the laboratory that undertook the measurements will be able to recognize their own results.

Participants were given detailed instructions and asked to analyze each data set to provide results for the following parameters, calculated in accordance with the definitions in EN 10002-1:

- 0.1% Proof Stress, $R_{p0.1}$, (MPa)
- 0.2% Proof Stress, $R_{p\,0.2}$, (MPa)
- Upper Yield Stress R_{eH}, (MPa)
- Lower Yield Stress, R_{eL}, (MPa)
- Tensile Strength, R_m, (MPa)
- Maximum Force, F_m, (N)
- Percentage Elongation after Fracture, A, (%)
- Percentage Total Elongation at Fracture, A_t (%)
- Percentage non-proportional elongation at maximum force, A_g, (%)
- Percentage total elongation at maximum force, A_{gt}, (%)
- Yield Point Extension, A_e (%)

If possible, participants were also asked to report the values for:

- Young's Modulus (from the slope of the load-extension or stress-strain curves) and the specific stress range over which this was calculated (if appropriate)
- Strain values at which point the proof or yield stresses were determined, (e.g. $A_{0.1}$, $A_{0.2}$, A_{eH}, & A_{eL}).

and note whether any smoothing or filtering of the data had been undertaken

Although these latter values and information are not a requirement of the Standard, it was deemed important as they might assist in explaining any inter-laboratory discrepancies. The default spreadsheet for return of the results is shown in Table A4 in the Appendix. Cells marked with an 'x' indicate that no values were expected for that particular material and parameter in the Table.

An initial assessment of the returns can be summarised thus:

- Not all organisations completed the analysis on the full dataset
- Different levels of precision were quoted
- Some organisations applied rounding to the results
- Some organisations used default values for E for the calculation of $R_{p0.1}$ & $R_{p0.2}$
- Only 2 organisations applied smoothing, where appropriate
- Some organisations returned values for parameters that were not appropriate for the particular material behaviour

Organisations were also encouraged to comment on their data, particularly if there were problems or difficulties with a test or in measuring a particular parameter, or whether an approach different to that recommended in the Standard was used. A summary of the results, observations and conclusions from the exercise, together with some recommendations for inclusion in future revisions of EN 10002-1 are given in the following sections.

6 RESULTS

6.2 STRATEGY FOR ANALYSING THE DATA

All the results were sent to NPL for collation and analysis. Throughout the duration of the project, updates were reported to the main project consortium at the 6-monthly project meetings, and a separate WP2 ASCII subgroup was formed to discuss the values and issues in more detail.

The strategy adopted for the analysis of the data involved the following approach …

1. Collate and analyse all the data, including uncertainties, without removing outliers
2. Agree the outliers with WP2 working group for each datafile
3. Agree **definitive** values for R_{eH}, R_{eL}, R_m and F_m
4. Agree a **range of values** for E, $R_{p0.1}$, $R_{p0.2}$ and A
5. Calculate the uncertainties on the “refined” dataset (without outliers) for comparison with Step 1Discard any datafiles that had ambiguities or problems with the analysis
7. Highlight issues and recommendations for input into the Standards committee
8. Agree a final subset of **Premium Quality** datafiles
9. Prepare the dataset for distribution on CD and via the project website

6.3 INITIAL ANALYSIS OF THE FULL DATASET

Table 4 shows the results returned for 3 representative datafiles, without removing any outliers. The uncertainty values for each parameter (but not including $A_{0.1}$, $A_{0.2}$, A_{eH}, & A_{eL}, which were provided for information only) are summarized in Table 5, and were calculated from twice the standard deviation for a given data set, representing the uncertainty at the 95% confidence limit. The uncertainty values are expressed as a percentage of the mean value of the relevant parameter. The cells have been colour coded for presentation purposes, highlighting uncertainties in the range 1-2% (yellow), 2-5% (orange) and over 5% (red). Uncertainty values below 1% are not highlighted.

Figure 4 shows the uncertainty values for the parameters of interest, grouped according to file number and material type. The data are presented in pairs, such that the first is the 50Hz datafile and the second are the results from the corresponding 5Hz file. Note that the figures are not plotted to the same scale and from this initial assessment it is clear that there are issues with measuring some of the parameters (e.g. modulus and elongation show large uncertainties and scatter), and that particular datafiles are giving problems.

It is important to remember at this stage that the data is from a single test and the results **do not include** any factors due to material variability or different test conditions. All the participants are analyzing the same data, which they are converting into stress-strain data, and the uncertainty in the values is associated solely with the software and the analysis methods used. As we will see later however, following a more rigorous assessment of the data and inspection of the individual load-extension and stress-strain curves, in many cases a significant contribution to the uncertainty has arisen because of problems encountered during testing (eg premature speed change), poor quality data, and different interpretations of the Standard.

Table 4: Examples of the analysis returns for 3 ASCII datafiles

Nimonic 75, CRM 661, 50 Hz			CRM 661-GBX 178-1												
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2
1	1	303.99	309.87			764.36	59972.7	41.22	41.5	30.81	31.18		208	0.25	0.35
2	1	303.84	309.88			764.36	59971.6856		34	30.55	31.18		210.156	0.24	0.35
3	1	304.57	310.1			764.36	59971.6856		34	30.52	31.18		200	0.25	0.35
4	1	303.8	309.8			764.4	59972.73	41.2	41.5	30.8	31.2		211	0.2	0.3
5	1	303.8	309.768			764.4	59973	41.229	41.495	30.8	31.2		211.862	0.243	0.346
6	1	303.8689	309.8033			764.3495	59971.9	41.2031	41.4726	30.9854	31.3489		210.3043	0.24516	0.34799
7	1	304.2	309.9			764.4	59973	41.2	41.5	31.1	31.5		205.5	0.249	0.349
8	1	304.927	309.706	764.708		764.708	60000		41.4		30.7		200.848	0.252	0.354
9	1	303.9	309.8			764.4	59973	41.24	41.496	30.814	31.178		210.05	0.245	0.348
10	1	303.86	309.8			764.36	59972.7	41.23	41.5	30.81	31.18		210.7	0.25	0.35
11	1	304.2	310			764.3	59970.99	41.15	41.43	30.91	31.28		202.85	0.25	0.35
12	1	303.9	309.8			764.4	59970	41.2	41.5	30.8	31.2		210.1	0.245	0.348
13	1	303	310			764	59900	41	41.5	31	31.5		216.5	0.2	0.3
14	1	303.94	309.84			764.36	59972.73	41.22	41.50	30.81	31.18		208.82		

Aluminium Sheet, 50 Hz			VAW-hard AA5182-No3-2												
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2
1	38	385.51	396.53			434.31	2006.5	4.73	5.35	4.32	4.95		69	0.66	0.77
2	38	384.59	396.14			434.31	2006.5122		5.48		4.94		68.826	0.65	0.76
3	38	382.78	395.44			395.44	1826.9328		5.48		4.94		70	0.63	0.75
4	38	385.3	396.4			434.3	2006.532959	4.7	5.3	4.3	4.9		69	0.7	0.8
5	38	385.219	396.397			434.3	2006.5	4.732	5.354	4.3	4.9		69.32	0.656	0.772
6	38	385.6295	396.5263			434.3145	2006.5	4.7184	5.3727	4.3091	4.9386		68.9826	0.65209	0.76788
7	38	386.3	396.8			434.3	2007	5.5	5.5	4.3	4.9		68.1	0.657	0.773
8	38	385.822	396.645	433.441		433.441	2002.5		5.343		5.3437		68.903	0.654	0.77
9	38	385.6	396.5			434.3	2007	4.7375	5.475	4.309	4.939		68.98	0.6538	0.7688
10	38	385.59	396.52			434.31	2006.53	4.628	5.251	4.309	4.939		69.03	0.66	0.78
11	38	386.2	396.8	404.11	398.2	428	1977.21	4.69	5.31	4.31	4.93	4.03	68.26	0.66	0.77
12	38	385.4	396.5	404.1	398.3	434.3	2007	4.7	5.4	4.3	4.9		69.2	0.651	0.767
13	38	385	397			435	2000	5	5	4	5		69	0.6	0.7
14	38	386.29	396.84	404.11	398.03	434.31	2006.53	4.72	5.36	0.27	0.86		68.16		

Sheet steel, 50 Hz			TKS-ZStE-180-L050-B12-5-Probe 1												
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2
1	53	246.82	230.1	270.06	231.94	318.86	3781.6	40.37	40.39	18.93	19.09	1.74	204	0.22	0.31
2	53			270.06	228.66	318.86	3781.6796		40.82	18.86	19.08	1.93	198.653		
3	53			270.06	228.66	318.86	3781.6796		40.82	18.86	19.08	1.93	200		
4	53			270.1	228.7	318.9	3781.637451	40.8	40.8	18.9	19.1	1.8	204		
5	53			270.064	233.633	318.9	3781.6	38.164	38.261	18.9	19.1	1.781	206.201		
6	53			270.0642	231.9365	318.713	3779.9	37.9818	38.0947	18.6555	18.8118	1.65386	203.9792		
7	53	247.4	230.2	270.1	228.7	318.9	3782	40.8	40.8	18.9	19.1	1.801	203.8	0.214	0.309
8	53	245.53	230.016	265.767		318.718	3780		38.1		16.65		203.73	0.218	0.31
9	53			270.6	228.2	318.9	3782	40.86	40.821	18.925	19.083	1.842	200.75		
10	53	245.02	230.34	270.06	228.66	318.86	3781.64	38.07	38.17	18.93	19.08	1.739	204.2	0.22	0.31
11	53	246.9	230	270.06	231.9	318.6	3779.01	40.71	40.71	18.65	18.8	2.97	208.94	0.22	0.31
12	53			270.1	231.9	318.9	3782	40.8	40.8	18.9	19.1		204		
13	53			270	232	319	3782	40.5	40.5	19	19	1.76	204		
14	53			270.06	228.66	318.86	3781.64			18.93	19.09		204.04		

Table 5: Summary of uncertainty values (± 2 standard deviations, ie 95% confidence level expressed as a percentage) for complete ASCII dataset (including outliers)

Dataset	Material	File Name	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	E
1	Nimonic 75, CRM 661	CRM 661-GBX 178-1	0.3	0.1			0.0	0.1	0.3	13.4	1.0	1.2	4.4
3	Nimonic 75, CRM 661	CRM 661-GBX 178-1	0.6	0.5			0.0	0.0	0.1	2.8	1.1	1.6	4.4
6	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	0.3	0.2			0.0	0.0	0.6	0.4	0.7	2.2	6.2
8	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	0.5	0.1			0.0	0.0	0.1	2.7	1.2	2.1	6.3
10	13%Mn Steel	P1M 23-2	0.3	0.1			0.4	0.4	1.0	1.2	6.8	6.8	5.2
12	13%Mn Steel	P1M 23-2	0.3	0.1			1.0	1.0	0.6	0.5	3.0	2.8	5.7
13	S355 Structural steel	P1M 24-1			0.1	0.7	0.0	0.0	0.6	14.3	1.0	4.4	9.1
15	S355 Structural steel	P1M 24-1			0.0	0.7	0.0	0.0	13.8	19.6	1.5	4.3	6.9
17	316L Stainless Steel	S1C 20-1	1.5	0.8			0.0	0.0	0.4	6.4	0.7	0.8	12.3
19	316L Stainless Steel	S1C 20-1	1.6	0.9			0.0	0.0	0.2	2.2	0.6	0.6	13.5
22	Tin Coated packaging steel	SOLLAC F72-No7-2	1.9	0.7			0.1	0.1	10.7	295.2	12.5	289.5	8.5
24	Tin Coated packaging steel	SOLLAC F72-No7-2	2.4	0.9			0.0	0.0	23.7	28.8	70.6	5.7	11.9
26	Sheet steel	SOLLAC T462 No6-2			0.4	0.6	8.6	8.4	5.1	294.2	236.2	223.0	2.0
28	Sheet steel	SOLLAC T462 No6-2			0.5	0.0	8.5	9.9	0.9	57.1	221.3	125.6	1.4
30	Sheet steel	TKS-DX56 No 2-2	0.5	0.2			0.1	0.0	1.4	1.6	0.9	3.6	11.7
32	Sheet steel	TKS-DX56 No 2-2	0.6	0.1			0.0	0.0	2.0	2.8	2.2	4.0	11.4
34	Sheet steel	TKS-ZStE-180-No1-2			1.3	1.9	0.0	0.0	15.9	1.6	1.1	4.4	2.3
36	Sheet steel	TKS-ZStE-180-No1-2			1.4	1.7	0.0	0.0	1.9	2.9	2.8	8.2	2.0
38	Aluminium Sheet	VAW-hard AA5182-No3-2	0.5	0.2			4.8	4.8	10.3	4.8	61.9	47.2	1.4
40	Aluminium Sheet	VAW-hard AA5182-No3-2	0.4	0.2			4.2	4.2	0.2	4.1	44.4	68.8	1.5
42	Aluminium Sheet	VAW-soft AA1050 No 5-2	9.4	2.4			0.3	0.0	2.0	1.7	2.4	4.6	10.2
44	Aluminium Sheet	VAW-soft AA1050 No 5-2	10.0	2.4			0.1	0.0	2.8	2.8	3.1	5.0	11.6
46	Aluminium Sheet	VAW-soft AA5182 No 4-2	0.3	0.2			0.9	0.9	2.2	1.2	59.4	56.3	1.5
48	Aluminium Sheet	VAW-soft AA5182 No 4-2	0.1	0.1			1.0	1.0	2.7	2.9	39.7	37.4	1.4
50	Sheet steel	TKS-DX56-L050-B12-5-Probe 2	1.1	0.3			0.1	0.7	1.4	1.3	0.4	5.4	16.0
52	Sheet steel	TKS-DX56-L050-B12-5-Probe 2	0.9	0.4			0.1	0.0	1.9	62.4	1.8	5.5	17.9
53	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 1			0.9	1.7	0.1	0.1	6.4	6.2	1.1	6.9	2.5
55	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 1			0.1	1.6	0.0	0.0	7.6	8.3	2.2	6.9	2.4
57	Synthetic Digital Curve	NPL Zero Noise	0.1	0.1			0.0	0.0	0.1	0.1	0.7	3.6	2.0
58	Synthetic Digital Curve	NPL Zero Noise	0.3	0.5			0.0	0.0	0.5	0.4	0.8	3.7	2.2
61	Synthetic Digital Curve	NPL 0.5% Load Noise	1.0	1.4			0.9	0.9	0.3	1.2	0.8	4.8	3.1
62	Synthetic Digital Curve	NPL 0.5% Load Noise	1.3	0.8			0.5	0.5	0.6	1.1	3.3	2.7	7.7
63	Synthetic Digital Curve	NPL 1% Load Noise	0.6	2.7			55.5	55.5	0.3	0.2	1.4	1.0	6.2
64	Synthetic Digital Curve	NPL 1% Load Noise	0.5	1.2			1.4	1.4	0.6	0.6	65.5	61.8	8.2

Uncertainty	1-2%	2-5%	Above 5%

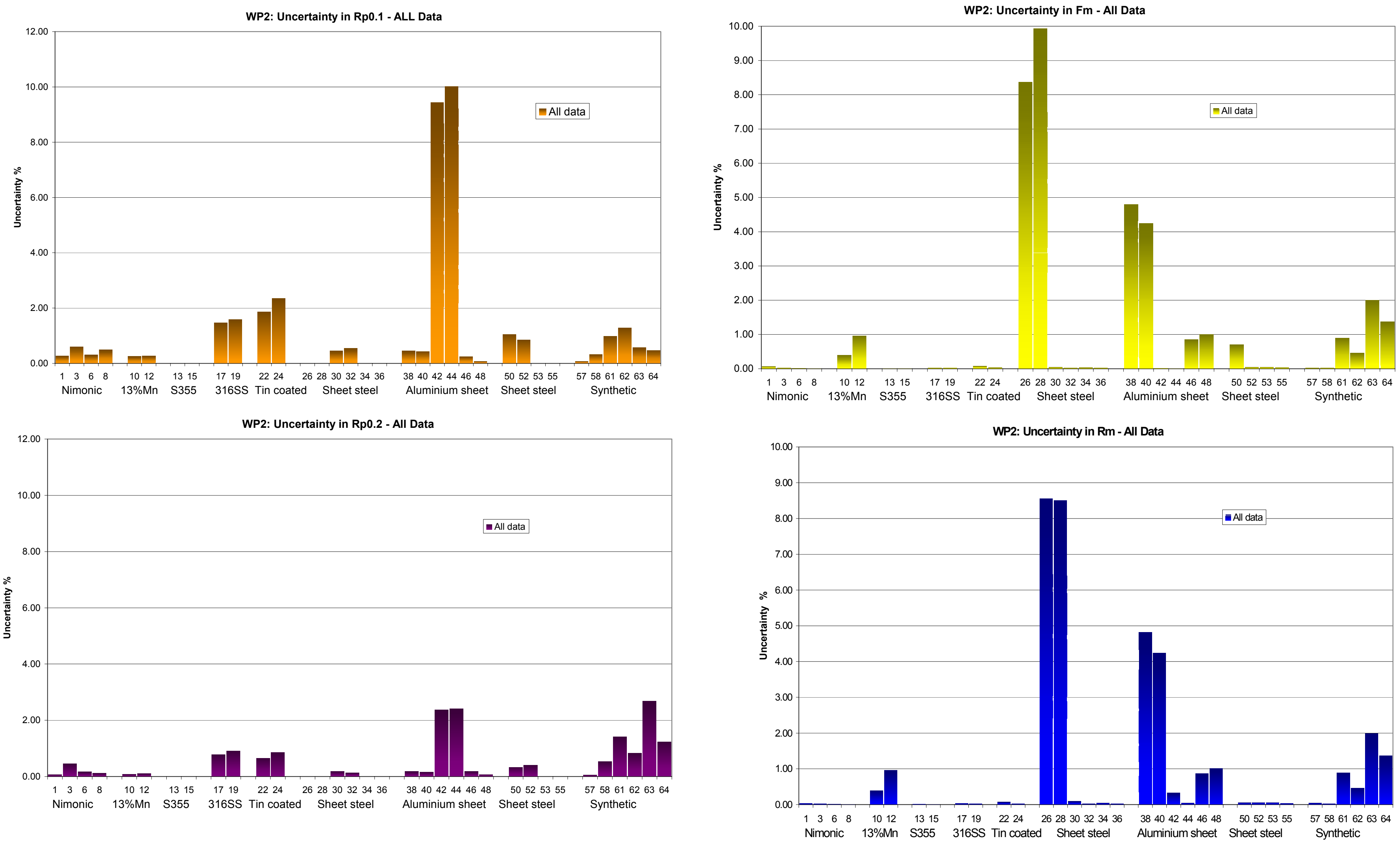


Fig 4: Uncertainty (expressed as 95% confidence limit) for parameters – ALL Data (including outliers)

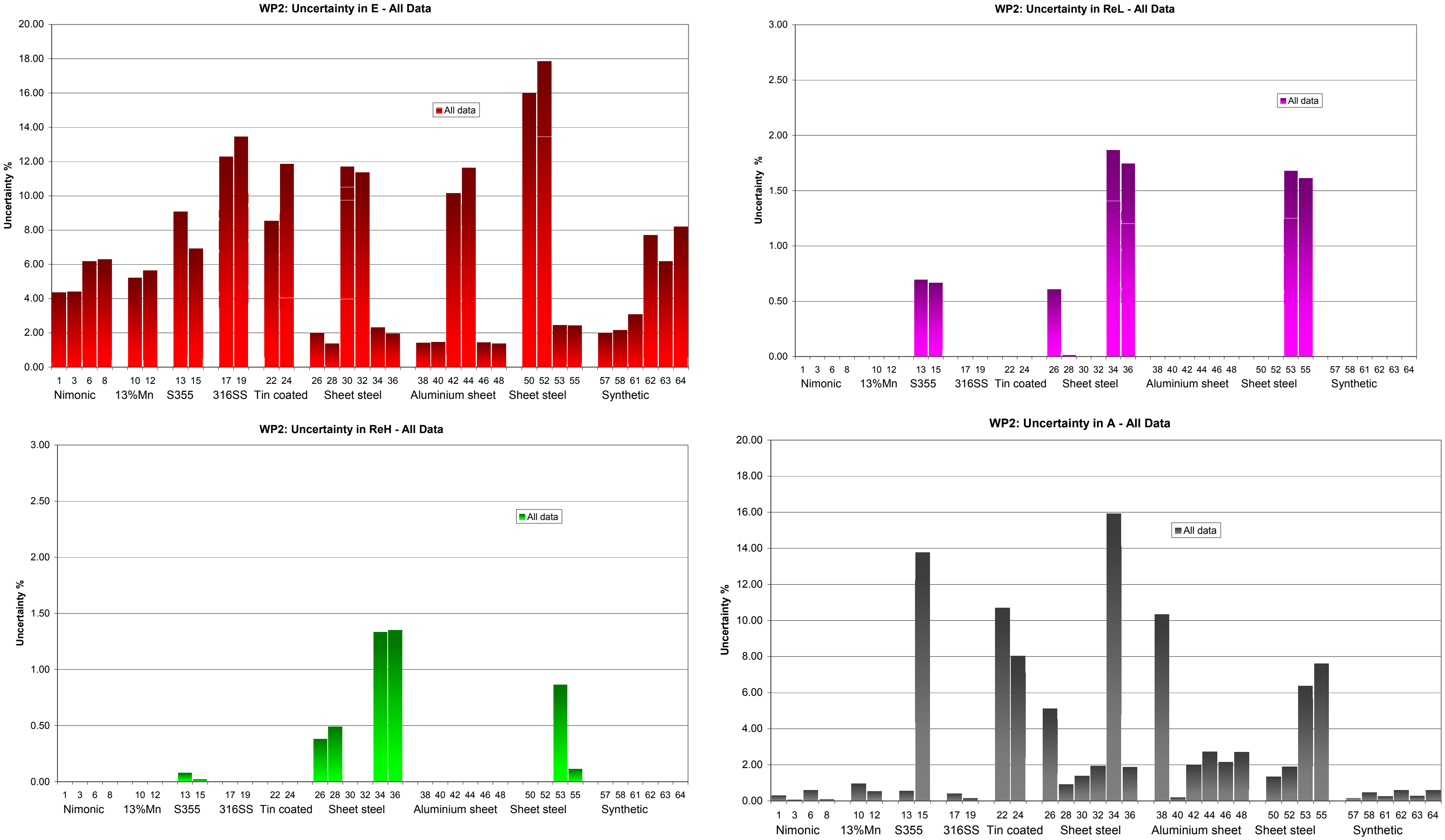


Fig 4 (contd): Uncertainty (expressed as 95% confidence limit) for parameters – ALL Data (including outliers)

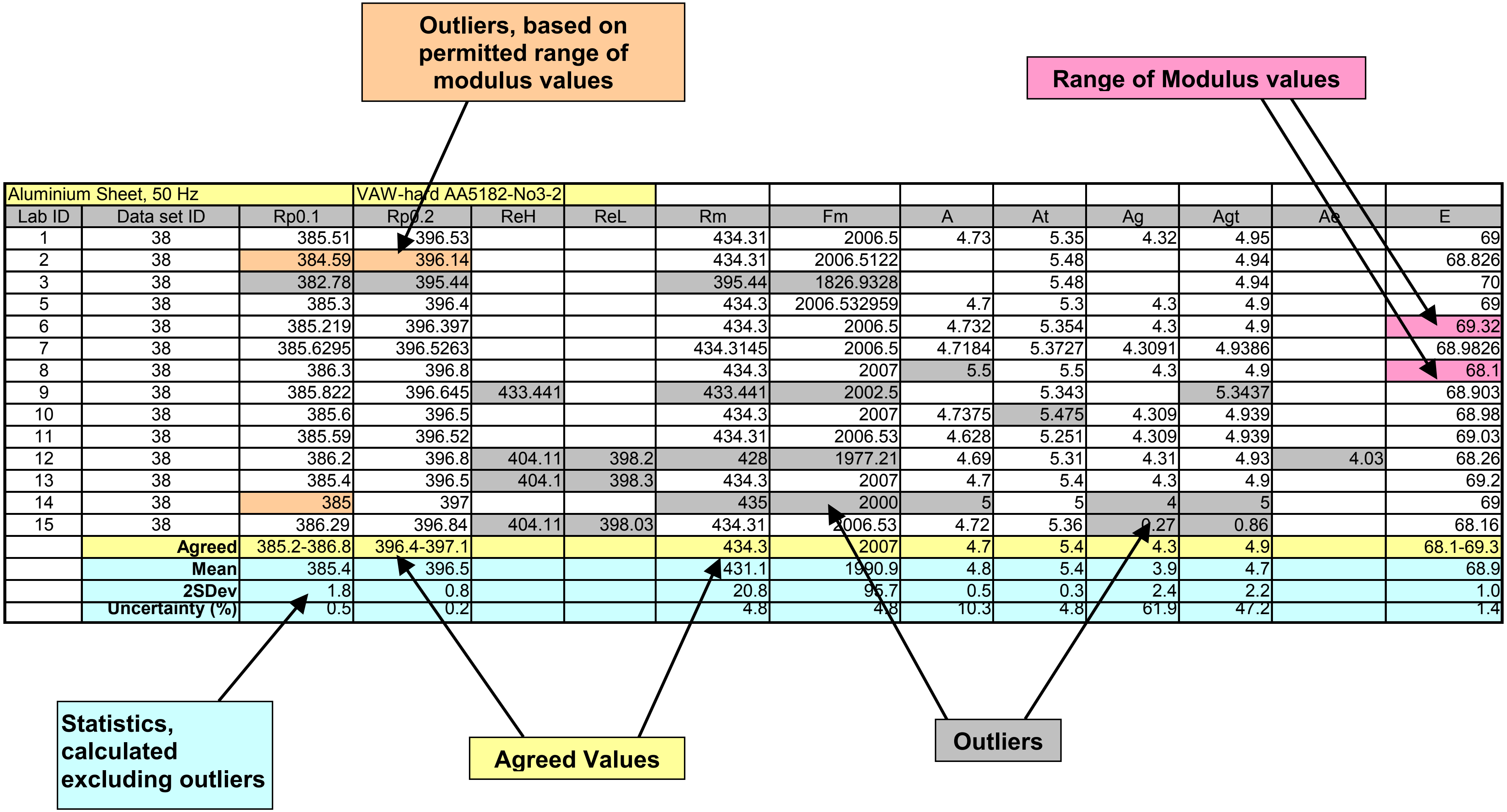
6.3 IDENTIFICATION OF OUTLIERS AND AGREED VALUES

The identification of outliers and the agreed values was a two-stage process. Initially the results were inspected for obvious errors and mistakes, and these values were removed or corrected. A rigorous assessment for outliers, such as that proposed by the Cochran test, was not carried out, but the agreed values and outliers for each datafile were chosen by careful examination of the data and inspection of the individual stress-strain curves. This was not a trivial task, and a separate WP2 meeting was held at NPL in July 2003 to discuss the data and agree values for all the files – even then less than half were covered. Further iterations and lengthy communications with the project partners followed to reach agreement. For some parameters - such as the maximum force and tensile strength - an absolute value (in most cases) could be agreed, but for others such as the modulus (with the exception of the synthetic data with zero noise presented in Files 57 and 58) a range of values were quoted. It is important to note that there is some interdependency of parameters such that modulus (slope) values also have an impact on the $R_{p0.1}$ and $R_{p0.2}$ values, and the associated values of $A_{0.1}$, $A_{0.2}$, A_{eH}, & A_{eL}. Where appropriate these are also presented as a range of values.

Despite detailed instructions regarding the precision and rounding, several participants did not adhere to the request and the returned values show considerable variations in this respect. Agreed values for the ASCII dataset are presented here to one level of precision higher than that specified in Section 17 of EN 10002-1 – for example stress values are reported to the nearest 0.1 MPa, force to the nearest 1 N and strains to the nearest 0.1%.

Table 6 below shows the database page for File 38, the AA5182 Aluminium sheet. All the data are included as before, but in this table the grey cells identify the outliers and these values have not been included in the subsequent uncertainty or statistical analyses. The full set of results from all the files is given in the spreadsheet in Appendix B. The pink cells show the upper and lower modulus (slope) values selected for each file. These values were selected by analyzing each curve using the NPL modulus software developed in WP3 and selecting a range of representative values that gave a reasonable visual fit to the early part of the curve. Typically the variation in modulus expressed by the range is 4-5%. Based on these modulus values, a corresponding range of values for $R_{p0.1}$ and $R_{p0.2}$ was calculated. Cells coloured in orange represent proof stresses that fall outside the range calculated using these modulus values - these are also excluded from the uncertainty and statistical analyses. The yellow coloured rows give the agreed values for the parameters for each material, either as a single value or a range (as appropriate). The rows beneath show the statistics - mean values, standard deviation and uncertainty (expressed as twice the standard deviation, representing the 95% confidence limit) for each parameter. The latter values are plotted in Fig 5 and summarized in Table 7, as before.

Table 6: ASCII datafile analysis



Outliers, based on permitted range of modulus values

Range of Modulus values

Aluminium Sheet, 50 Hz			VAW-hard AA5182-No3-2										
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E
1	38	385.51	396.53			434.31	2006.5	4.73	5.35	4.32	4.95		69
2	38	384.59	396.14			434.31	2006.5122		5.48		4.94		68.826
3	38	382.78	395.44			395.44	1826.9328		5.48		4.94		70
5	38	385.3	396.4			434.3	2006.532959	4.7	5.3	4.3	4.9		69
6	38	385.219	396.397			434.3	2006.5	4.732	5.354	4.3	4.9		69.32
7	38	385.6295	396.5263			434.3145	2006.5	4.7184	5.3727	4.3091	4.9386		68.9826
8	38	386.3	396.8			434.3	2007	5.5	5.5	4.3	4.9		68.1
9	38	385.822	396.645	433.441		433.441	2002.5		5.343		5.3437		68.903
10	38	385.6	396.5			434.3	2007	4.7375	5.475	4.309	4.939		68.98
11	38	385.59	396.52			434.31	2006.53	4.628	5.251	4.309	4.939		69.03
12	38	386.2	396.8	404.11	398.2	428	1977.21	4.69	5.31	4.31	4.93	4.03	68.26
13	38	385.4	396.5	404.1	398.3	434.3	2007	4.7	5.4	4.3	4.9		69.2
14	38	385	397			435	2000	5	5	4	5		69
15	38	386.29	396.84	404.11	398.03	434.31	2006.53	4.72	5.36	0.27	0.86		68.16
	Agreed	385.2-386.8	396.4-397.1			434.3	2007	4.7	5.4	4.3	4.9		68.1-69.3
	Mean	385.4	396.5			431.1	1990.9	4.8	5.4	3.9	4.7		68.9
	2SDev	1.8	0.8			20.8	95.7	0.5	0.3	2.4	2.2		1.0
	Uncertainty (%)	0.5	0.2			4.8	4.8	10.3	4.8	61.9	47.2		1.4

Statistics, calculated excluding outliers

Agreed Values

Outliers

Table 7: Summary of uncertainty values (± 2 standard deviations, ie 95% confidence level expressed as a percentage) for the ASCII dataset (mean values exclude Files 26,28) – Outliers excluded

Dataset	Material	File Name	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	E
1	Nimonic 75, CRM 661	CRM 661-GBX 178-1	0.1	0.1			0.0	0.0	0.3	0.2	0.4	0.2	3.9
3	Nimonic 75, CRM 661	CRM 661-GBX 178-1	0.2	0.0			0.0	0.0	0.1	0.0	0.7	0.3	4.4
6	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	0.2	0.1			0.0	0.0	0.6	0.4	0.7	2.2	4.0
8	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	0.2	0.1			0.0	0.0	0.1	2.7	0.8	0.4	3.9
10	13%Mn Steel	P1M 23-2	0.1	0.0			0.0	0.0	0.3	0.8	0.7	0.2	1.1
12	13%Mn Steel	P1M 23-2	0.0	0.0			0.0	0.0	0.6	0.5	0.7	0.0	1.6
13	S355 Structural steel	P1M 24-1			0.0	0.0	0.0	0.0	0.6	0.4	1.0	4.4	2.4
15	S355 Structural steel	P1M 24-1			0.0	0.0	0.0	0.0	0.8	0.6	0.8	4.4	3.6
17	316L Stainless Steel	S1C 20-1	0.2	0.2			0.0	0.0	0.4	0.5	0.3	0.2	4.3
19	316L Stainless Steel	S1C 20-1	0.3	0.3			0.0	0.0	0.2	2.2	0.6	0.6	4.8
22	Tin Coated packaging steel	SOLLAC F72-No7-2	0.6	0.3			0.0	0.0	2.5	2.8	1.4	1.1	2.9
24	Tin Coated packaging steel	SOLLAC F72-No7-2	1.0	0.4			0.0	0.0	1.5	0.7	1.1	4.4	4.0
26	Sheet steel	SOLLAC T462 No6-2			0.0	0.0	6.6	8.4	5.1	1.3	193.9	223.0	1.8
28	Sheet steel	SOLLAC T462 No6-2			0.0	0.0	8.5	9.9	0.9	57.1	179.1	125.6	1.1
30	Sheet steel	TKS-DX56 No 2-2	0.4	0.2			0.0	0.0	0.9	0.9	0.5	0.3	4.0
32	Sheet steel	TKS-DX56 No 2-2	0.4	0.1			0.0	0.0	2.0	2.8	2.2	4.0	5.9
34	Sheet steel	TKS-ZStE-180-No1-2			0.0	0.1	0.0	0.0	0.8	1.3	1.1	1.2	2.3
36	Sheet steel	TKS-ZStE-180-No1-2			0.0	0.1	0.0	0.0	1.9	2.9	0.3	0.1	2.0
38	Aluminium Sheet	VAW-hard AA5182-No3-2	0.2	0.1			0.0	0.0	1.4	4.8	0.3	0.8	1.4
40	Aluminium Sheet	VAW-hard AA5182-No3-2	0.2	0.1			0.0	0.0	0.2	4.1	1.1	0.8	1.5
42	Aluminium Sheet	VAW-soft AA1050 No 5-2	0.1	0.1			0.1	0.0	0.3	0.7	0.4	0.1	5.8
44	Aluminium Sheet	VAW-soft AA1050 No 5-2	0.4	0.3			0.0	0.0	2.8	2.8	0.4	0.1	6.9
46	Aluminium Sheet	VAW-soft AA5182 No 4-2	0.3	0.2			0.1	0.0	0.2	1.2	0.9	0.2	1.5
48	Aluminium Sheet	VAW-soft AA5182 No 4-2	0.1	0.1			0.0	0.0	0.1	0.2	0.9	0.1	1.4
50	Sheet steel	TKS-DX56-L050-B12-5-Pr 2	0.5	0.1			0.0	0.0	1.4	1.3	0.4	0.2	3.5
52	Sheet steel	TKS-DX56-L050-B12-5-Pr 2	0.1	0.1			0.0	0.0	0.8	0.1	0.4	1.5	6.4
53	Sheet steel	TKS-ZStE-180-L050-B12-5-Pr 1			0.0	0.0	0.0	0.0	0.9	0.8	0.9	0.3	2.5
55	Sheet steel	TKS-ZStE-180-L050-B12-5-Pr 1			0.0	0.0	0.0	0.0	7.6	8.3	0.3	6.9	2.4
57	Synthetic Digital Curve	NPL Zero Noise	0.1	0.0			0.0	0.0	0.1	0.1	0.5	0.1	0.3
58	Synthetic Digital Curve	NPL Zero Noise	0.0	0.0			0.0	0.0	0.5	0.4	0.8	0.1	0.4
61	Synthetic Digital Curve	NPL 0.5% Load Noise	0.2	0.2			0.0	0.0	0.3	1.2	0.8	4.8	2.4
62	Synthetic Digital Curve	NPL 0.5% Load Noise	0.0	0.0			0.0	0.0	0.6	1.1	3.3	2.7	2.1
63	Synthetic Digital Curve	NPL 1% Load Noise	0.4	0.2			0.0	0.0	0.3	0.2	1.4	1.0	2.8
64	Synthetic Digital Curve	NPL 1% Load Noise	0.2	0.2			0.0	0.0	0.6	0.6	0.8	0.1	4.0
		Mean	0.2	0.1	0.0	0.0	0.0	0.0	0.8	1.3	0.8	1.4	3.1

Uncertainty	**1-2%**	**2-5%**	**Above 5%**

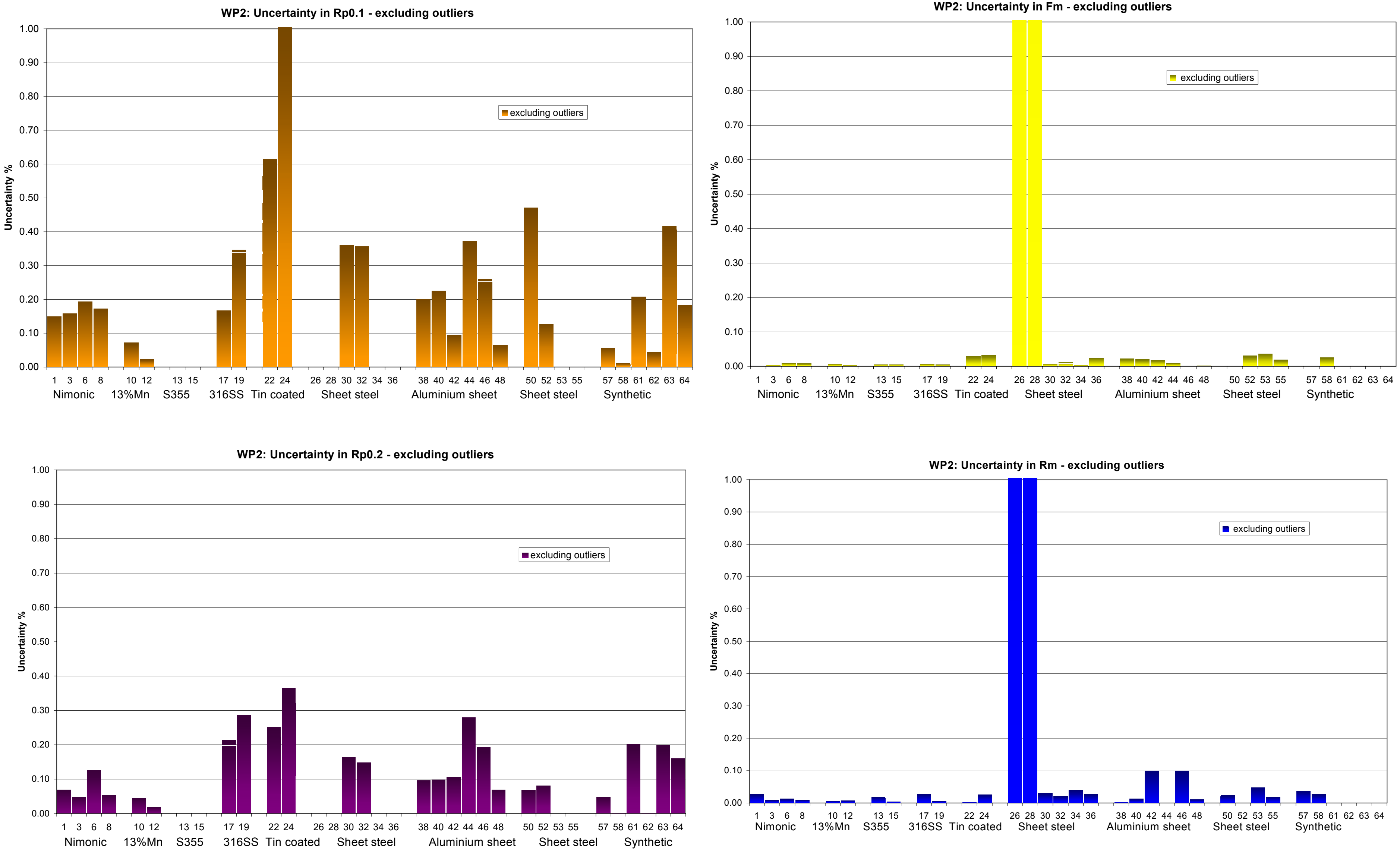
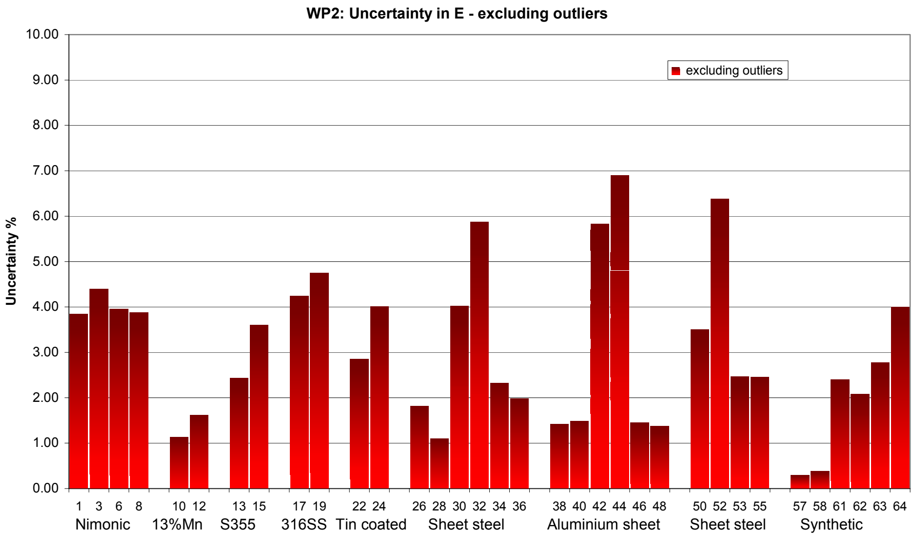
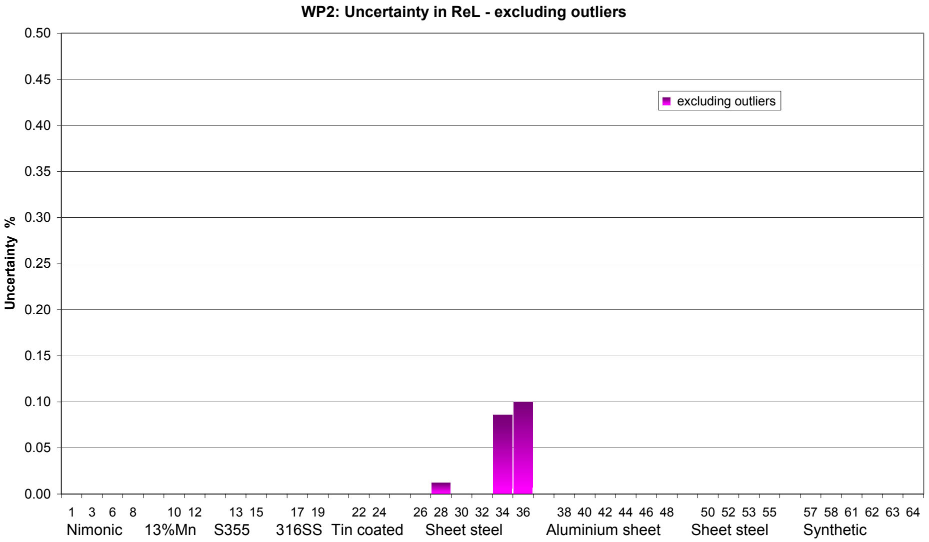
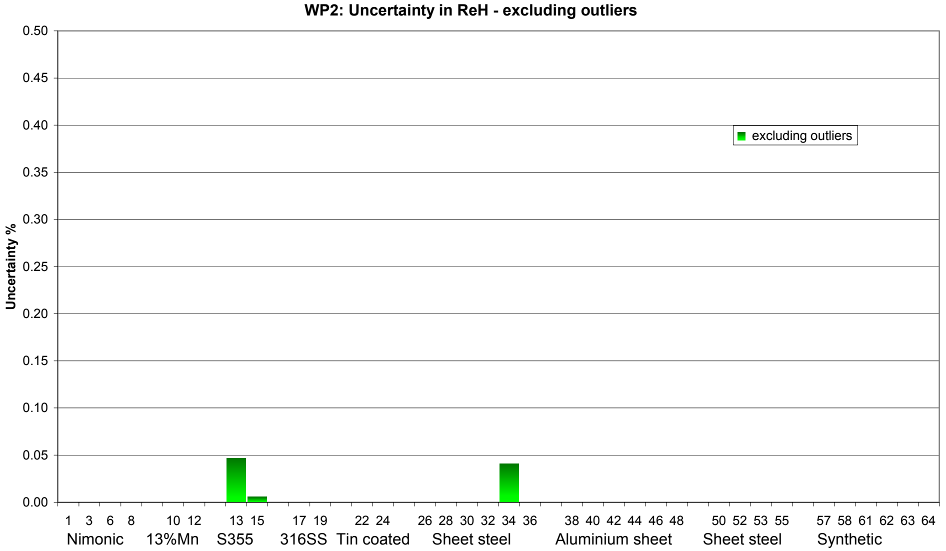


Fig 5: Uncertainty (expressed as 95% confidence limit) for parameters – Data excluding outliers







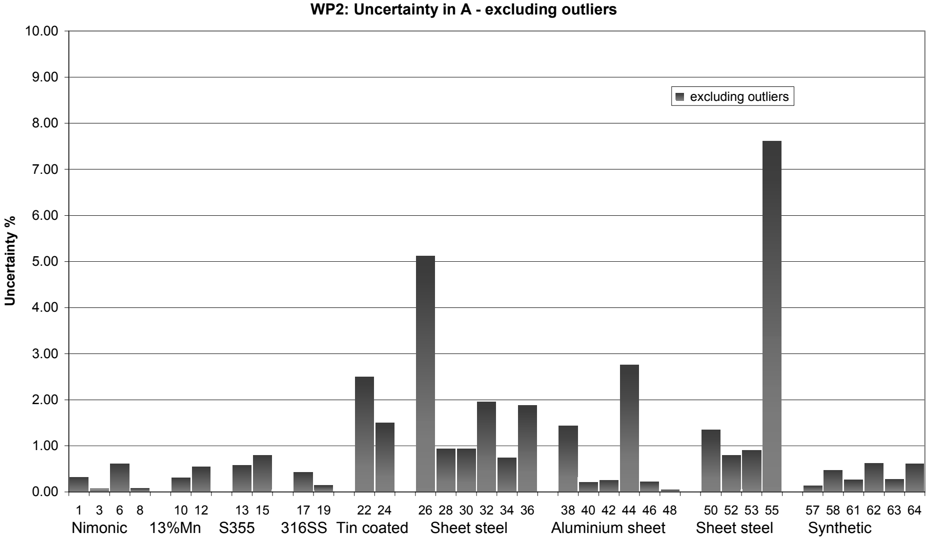


Fig 5 (contd): Uncertainty (expressed as 95% confidence limit) for parameters – Data excluding outliers

As might be expected, this data shows a significant reduction in uncertainty compared with the full data set. Data from Files 26 and 28 are not included in the mean uncertainty values due to anomalies during testing (see later). Files 34 and 36 are affected in the same manner, but in this case the difficulties associated with the test did not affect the values to the same extent, and these results are included in the statistics. Generally the uncertainty values are low, with the notable exception of the modulus, elongation and extension results. The proof stress values show some variability and in most cases the uncertainty in $R_{p0.1}$ values are greater than the $R_{p0.2}$. This is to be expected as the stress-strain curve at this point is generally steeper and any variation in modulus will have a greater impact on the calculated value for $R_{p0.1}$. The $R_{p0.1}$ values are also smaller than $R_{p0.2}$, so an equivalent error in modulus will have a larger effect in terms of the percentage uncertainty.

Surprisingly, the uncertainties associated with the total elongations at A_t and A_{gt} are generally a little lower than those calculated for the non-proportional equivalents (A and A_g respectively), which also rely to some extent on the slope of the initial part of the stress-strain curve. Perhaps not surprisingly, the uncertainty values for the 5Hz data tend to be higher than the corresponding 50 Hz data.

7 ISSUES, DIFFICULTIES AND REJECTED FILES

Even after careful and detailed inspection of the data and the individual load-extension and stress-strain curves, some files continued to give problems. It is clear from the results presented so far that in some cases there is considerable variation and uncertainties in the reported values, which is probably larger than might be expected for the software alone.

The main causes of the large uncertainty appear to be related to different interpretations of the definitions in the Standard, and to anomalies in the stress-strain curves sometimes caused by a premature change in the test conditions (speed or control mode). Some of the problems were specific to a particular material behaviour (for instance there were significant problems with two sets of files that showed upper and lower yield behaviour), whilst others (such as the large variation in the calculated values for modulus) were factors in all the datafiles.

Some of these issues are presented as examples in this section. They highlight some of the difficulties encountered by participants in the exercise and provide background to why some of the values and files were rejected. Where appropriate the relevant issues identified will be taken forward as part of the recommendations from WP2 for consideration by the Standards committee for inclusion in future revisions of EN 10002-1. The specific examples are:

Example 1 - Ambiguities in defining F_m and R_m (File 26)
Example 2 – Problems caused by a premature change of speed (Files 26, 34, 13)
Example 3 – Identifying a transient effect (Files 13, 53, 34)
Example 4 – Regarding the definition of A_e (File 13)
Example 5 – Effect of modulus variation on other parameters (Files 22, 1, 6)
Example 6 – Correcting for preloads and offsets (File 42)
Example 7 – The use of synthetic datafiles (File 57)
Example 8 – Scatter in identifying fracture point, A_t (File 30)

Example 9 – Smoothing and noise (Files 46, 61)
Example 10 – Relevance of 5Hz data sampling rate (Files 44, 15)

Examples 1-5 deal with specific issues, mainly associated with materials exhibiting upper and lower yield, and reflect the difficulties in correctly measuring some of the parameters. Examples 6-10 cover more general issues relevant to all material behaviour. The File numbers in brackets refer to specific examples chosen to illustrate the point. In many cases other datafiles show similar behaviour and attributes, and the issues are appropriate to a wide range of situations and cases.

Where appropriate, issues and recommendations are highlighted in bold and summarised in Section 10.

For information, a glossary of definitions for the various parameters, taken from the Standard, is given in Appendix A.

7.1 EXAMPLE 1 – AMBIGUITIES IN DEFINING F_M AND R_M (FILE 26)

Figure 6 below shows part of the stress-strain curve for File 26 for the T462 sheet steel, which exhibits upper and lower yield. The behaviour of this material is very different from the other materials that show this yield phenomena (Files 13, 34 & 53) as the stress-strain curve is very flat. Consequently there was some ambiguity with respect to the definition of the maximum force, F_m, leading to two very different values being selected – as indicated on the curve. The values returned from the software intercomparison are given in the spreadsheet in Appendix B.

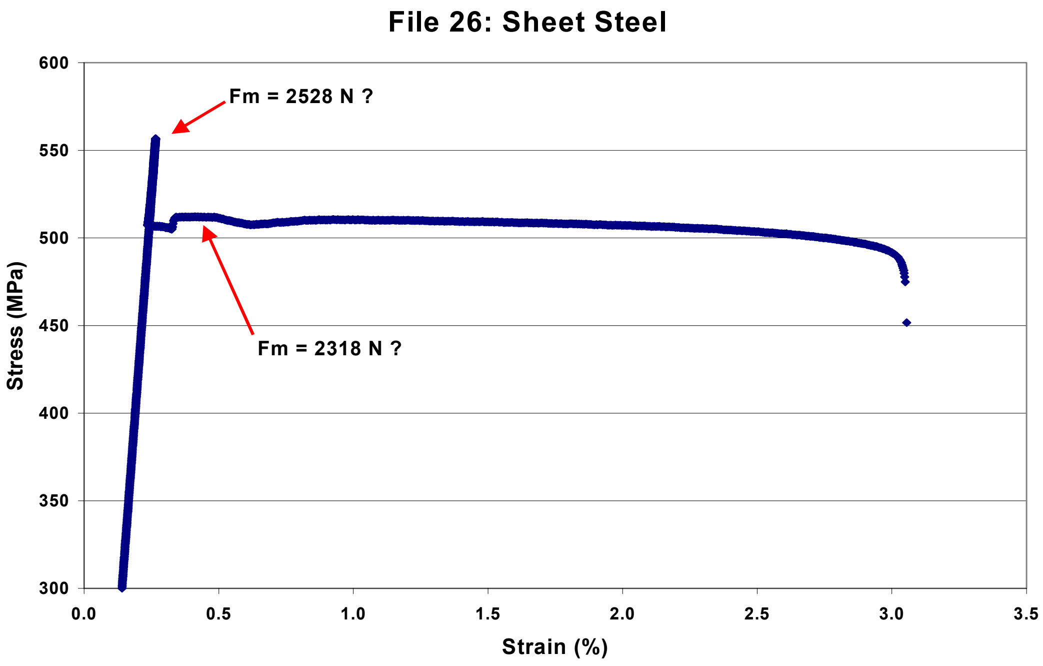


Fig 6: Example illustrating the ambiguities in defining F_m and R_m

According to the definition in section 4.8 of EN 10002-1, the **Maximum Force (F_m)** *is the greatest force that the testpiece withstands during the test once the yield point has been passed. For materials without yield point, it is the maximum value during the test.*

Taken literally, and using modern computer-controlled test machines with closed loop feedback and high data sampling rates, the value of 2528 N could correspond to the first data point immediately following the detection of upper yield (via a drop in the force) but the issue is whether this is the intention or is it a misinterpretation of the Standard. For this datafile the majority of participants chose the value of 2528 N for F_m, four selected 2318 N, and three other different values were selected.

There are further ambiguities when considering the **Tensile Strength (R_m)**, which is defined in Section 4.9.1 of EN 10002-1 as *the stress corresponding to the maximum force (F_m).* According to this definition, R_m = 556.7 MPa, but this is the same as the R_{eH} value. In fact, for this datafile, five different values for R_m were quoted including 556.7 MPa, 554.2 MPa, 549.3 MPa, 512.1 MPa and 510.5 MPa.

As will be explained in Example 2 below, the ambiguity of choosing between 512.1 MPa and 510.5 MPa has arisen because of a premature change in speed during the test, but the focus in this example is whether the value of 556.7 MPa or 510.5 MPa (or 512.1 MPa) is correct. The value of 556.7 MPa corresponds to the upper yield strength (R_{eH}), which all but two organisations identified correctly. It is interesting to note that whilst the value of R_m of 512.1 MPa is probably correct according to the definition currently given in the Standard, the supplier of the material in this case asserts that they would use the value of 510.5 MPa.

Thus there clearly appears to be ambiguity in the interpretation of the Standard concerning the measurement of F_m and R_m, and the definition of yield point. **Consideration should be given to amending the Standard, to clarify the definition of F_m and R_m, particularly for materials that exhibit upper and lower yield phenomena where ambiguities may arise.**

7.2 EXAMPLE 2 – PROBLEMS CAUSED BY A PREMATURE CHANGE OF SPEED (FILES 26, 34, 13)

Figure 7 below shows an expanded portion of the stress-strain curve for File 26 - the file that gave the WP2 working group the greatest difficulties. As mentioned above, the values reported for R_m and F_m showed considerable variation, and this is also true for R_{eL}. The ambiguity in the interpretation of R_{eL} is almost certainly associated with the premature change of speed, as indicated by the arrow on the graph, which led to a sharp jump in the stress-strain curve. Figure 8 shows the corresponding plot of stress and crosshead vs time, also showing the point of speed change.

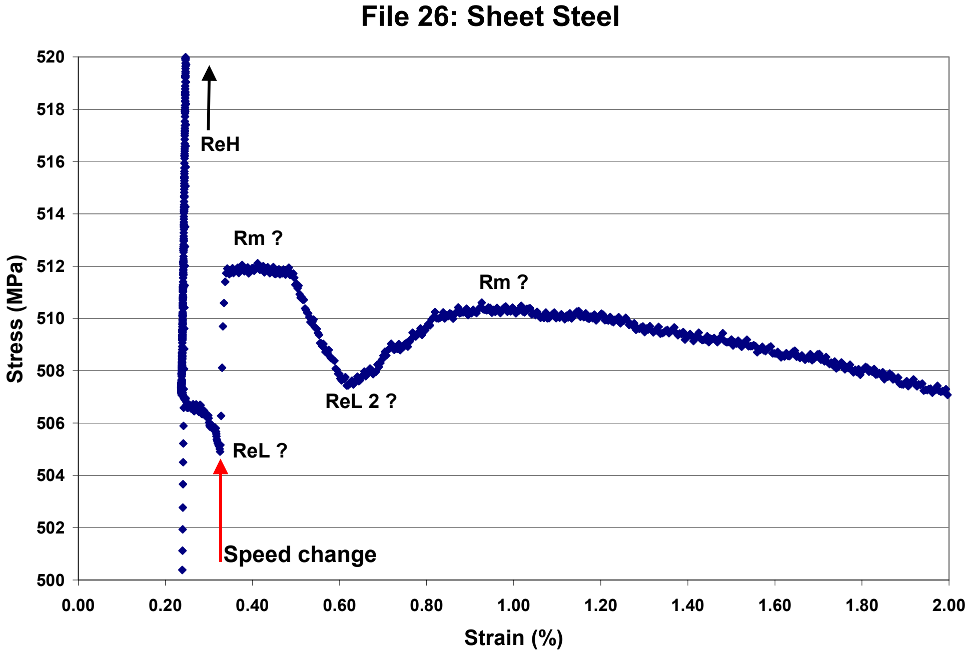


Fig 7: Example illustrating the different interpretation of values of R_{eL} and R_m

The identification of the upper yield point (R_{eH}) was not a problem, although as noted in Example 1, some organisations quoted the same value for R_{eH} and R_m. The **Upper yield strength (*R_{eH}*)** is defined in A.4.2 and 4.9.2.1 as *the stress corresponding to the highest value of force prior to a reduction of at least 0.5% of the force and followed by a region in which the force should not exceed the previous maximum over a strain range not less than 0.05%.*

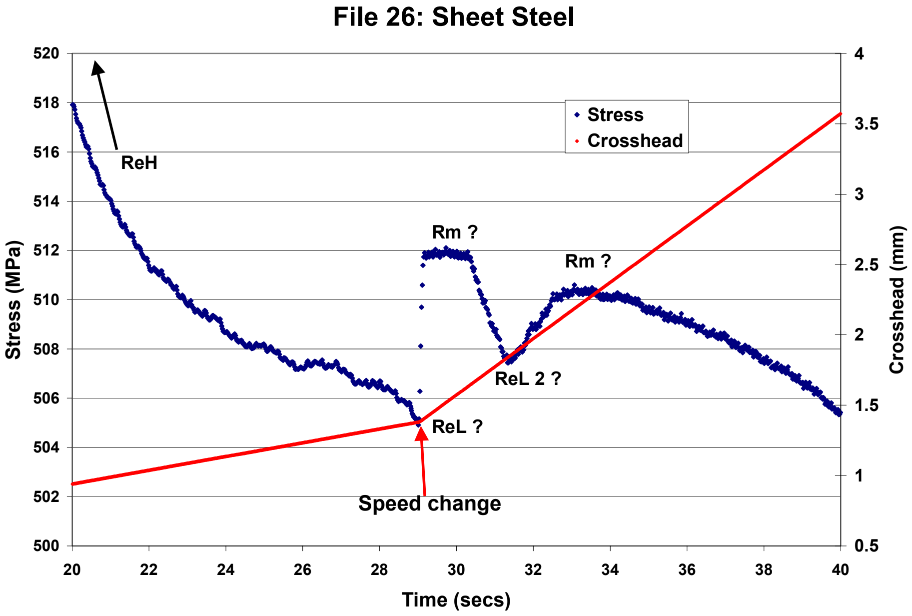


Fig 8: Corresponding plot of stress and crosshead vs time, showing the point of speed change

The **Lower yield strength (R_{eL})** is defined in 4.9.2.2 and A.4.3 as *the lowest value of stress during plastic yielding, ignoring any transient effects.* In this example most of the participants chose 504.9 MPa as the value for R_{eL}, and this is strictly correct according to the definition above. However, the premature speed change that occurred during plastic yielding has caused a jump in the stress-strain curve, without which the event marked by R_{eL2} would probably give the correct value. A similar problem occurred with File 34 shown in Fig 9 below. In this case values for R_{eL} of 236.7 MPa and 240.4 MPa were reported, but the point identified at 236.7 MPa occurs before the speed change.

Section 10.2 of EN 10002-1 specifies the rate conditions for the test. Specific guidance is given for the rate to be used within the elastic range and up to R_{eH} (10.2.2.1) and for tests where only R_{eL} is being measured (10.2.2.2). For the determination of R_{eH}, the test conditions are presented in terms of a stress rate, depending on the elastic modulus of the material being tested. For the determination of R_{eL} however the Standard states that *the strain rate during yield of the parallel length of the test piece shall be between 0.00025 s^{-1} and 0.0025 s^{-1} … **and that the strain rate shall be kept as constant as possible, the controls of the machine not being further adjusted until the completion of yield.***

Furthermore, Section 10.2.2.3 specifies that *if the two yield strengths are determined during the same test, the conditions for determining R_{eL} shall be complied with**. Only after the determination of the required yield or proof strength properties may the test rate be increased.***

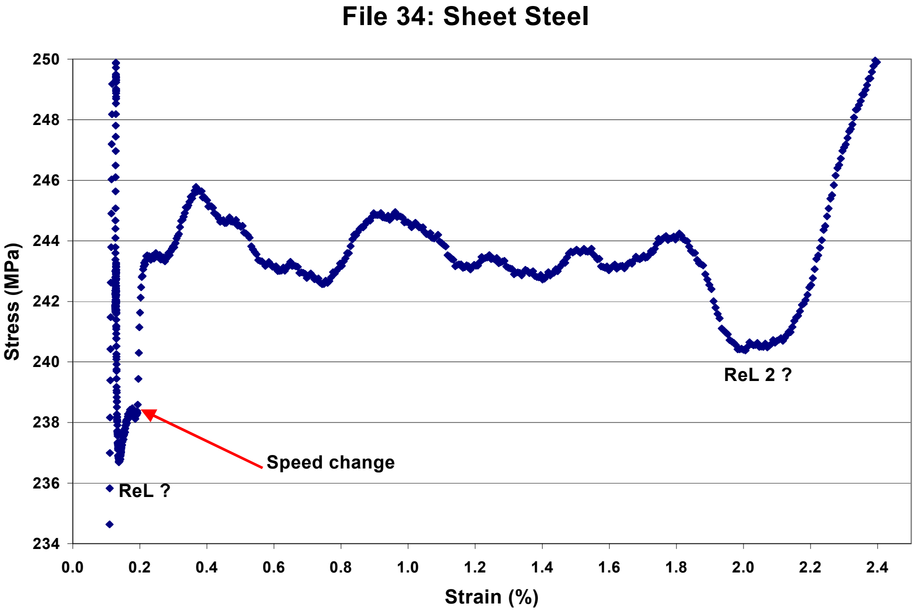


Fig 9: Curve showing alternative interpretations of the values of R_{eL}

Clearly these test rate conditions have not been followed in these cases (Files 26 & 34). Possible causes could be an incorrect manual selection of the point for speed change, or the over-sensitivity of the control software to noise and fluctuations in the load signal during yielding, which has triggered the premature change.

Section A.4.3 in Annex A has an additional clause and test condition. It states that ... *for productivity of testing a nominal value of* R_{eL} *may be reported as the lowest stress within the first 0.25% strain after* R_{eH}*, not taking into account any initial transient effect. After determining* R_{eL} *by this procedure, the test rate may be increased.*

As seen above, changing the speed during the early stages of plastic yielding can cause a significant shift in the stress-strain curve and introduce complications and anomalies with the identification of $\mathrm{R_{eL}}$. Although the effective changes in $\mathrm{R_{eL}}$ value may be small (typically 1-2%), results from this exercise indicate that it is not recommended practice to change speed prematurely.

A key recommendation for the Standards committee for materials that exhibit upper and lower yield phenomena, is to be more explicit and not allow a speed change until after $\mathrm{R_{eL}}$ has been reached, or define a set value of strain (e.g. 0.5%, 1% or 2%) at which this could be implemented.

Due to the problems caused by the premature change of speed and the interpretation of the Standard with respect to some of the parameters it was the recommendation of the WP2 group that Files 26 and 34 (and the corresponding 5Hz versions – Files 28 and 36) should not be included in the Premium Quality ASCII dataset.

The values for these files are presented in the Tables, but the strength and elongation values have not been included in the mean statistics and uncertainty calculations. In contrast to Files 26 and 34, the stress-strain curve in Fig 10, and the plot of stress and crosshead versus time in Fig 11 below, shows the data from File 13 for the S355 structural steel, where the speed change has been applied correctly after R_{eL}. In this case there were no significant issues with identifying R_{eL} and the corresponding uncertainty values for the file are significantly reduced compared with Files 26 and 34 presented previously.

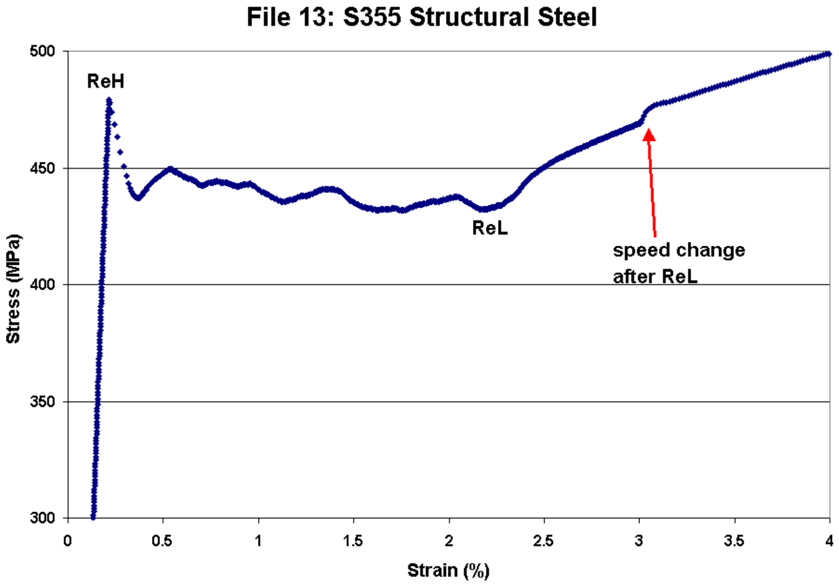


Fig 10: Good example of a curve with speed increase after $\mathrm{R_{eL}}$

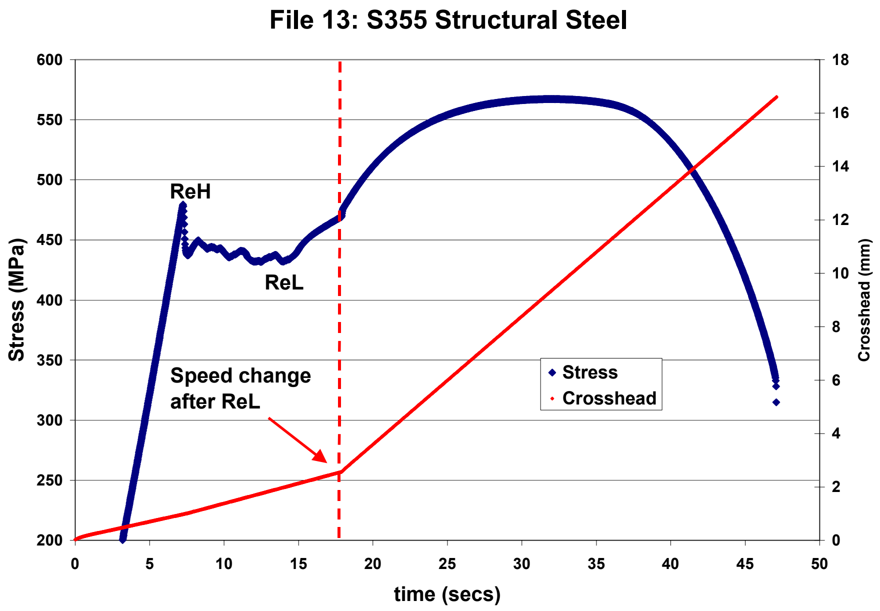


Fig 11: Stress and crosshead vs time curve showing the speed change after R_{eL}.

7.3 EXAMPLE 3 – IDENTIFYING A TRANSIENT EFFECT (FILES 13, 53, 34)

Figure 2 in EN 10002-1 includes examples showing the definition of R_{eH} and R_{eL} where there are “initial transient effects”. The figures are somewhat stylised, showing a regular waveform with slowly decaying amplitude, and in reality this is often not the case as shown in examples from Files 13 and 53 below, and File 34 (Fig 9) shown previously.

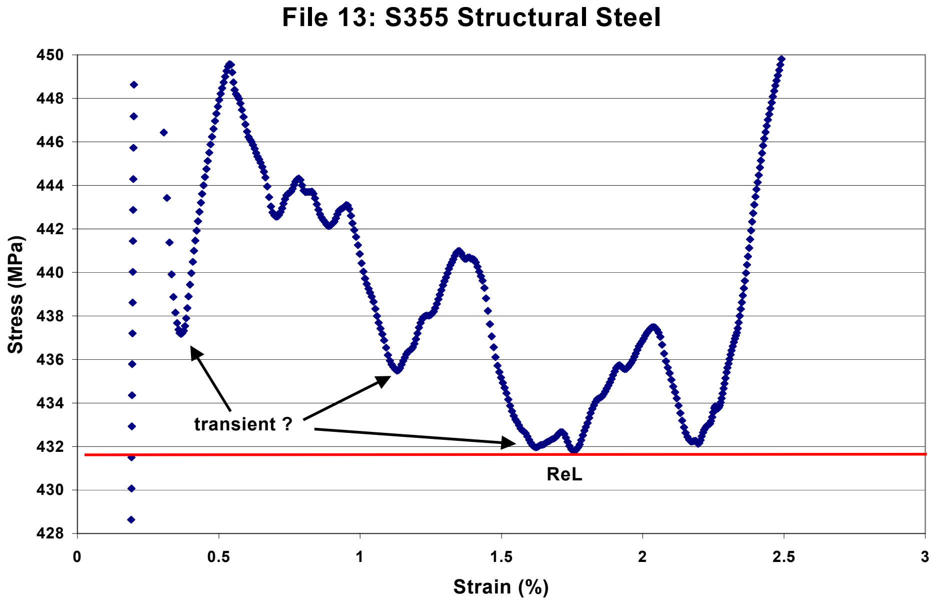


Fig 12: Transient effects and the impact on the selection of R_{eL} (File 13)

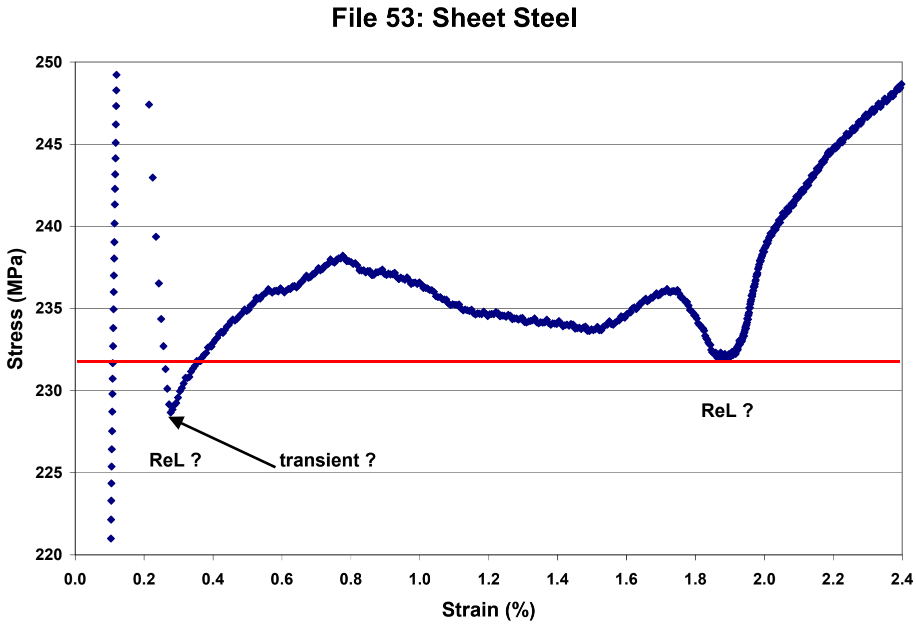


Fig 13: Transient effects and the impact on the selection of R_{eL} (File 53)

The WP2 group had some difficulty in agreeing what was meant by the definition of the "*initial transient effect"* in the Standard, and indeed its cause, although it is probably triggered by the onset of yielding in the testpiece, and is affected by a combination of the system compliance, the location of yielding in the testpiece, the material properties and test machine response. It is unclear whether the definition refers only to the first drop in load (as seems to be implied from Fig. 2 in the Standard) and whether subsequent variations should be ignored and assumed to be real material behaviour. This is an issue with File 13 (Fig. 12), although all but one laboratory selected the value of 431.8 MPa for R_{eL}. For File 53 (Fig. 13) there was less agreement, with about half of the participants identifying R_{eL} as 228.7 MPa, and the rest selecting 231.9 MPa. Assuming that the first load drop is the transient effect, then the value of R_{eL} = 231.9 MPa has been selected as the correct value in this case. For this file, different interpretations of the definition for R_{eL} have led to an uncertainty of over 1%.

It is also interesting to compare the stress-strain curves presented for File 34 (Fig 9) and File 53 (Fig 13) above as these are tests on the same material – the bake hardened steel sheet - carried out by different laboratories. Although File 34 is affected by the premature speed change, the tests have been carried out under nominally the same conditions, and the difference in detail and form of this part of the curve is almost certainly related to the differences in machine compliance, response and control. There is also a significant difference in R_{eL} values from the two tests – a factor that would be important in determining the uncertainty and repeatability of the material batch, but is not considered further in this study as the emphasis is on the generation and analysis of representative stress-strain curves.

To avoid ambiguities in the interpretation of the "initial transient effect", it is recommended that the Standards committee consider expanding and clarifying the definition, including more realistic examples where appropriate.

7.4 EXAMPLE 4 – REGARDING THE DEFINITION OF A_E (FILE 13)

File 13 is also useful for examining the issues regarding the definition and identification of the percentage yield point extension (A_e), as indicated in Fig 14 below.

According to Section A.4.7 of EN 10002-1, the **percentage yield point extension (A_e)** *requires assessment of the 2 points that define the beginning and end of the yield point extension. The beginning is at that point where the slope becomes zero and is represented by a horizontal line. The end point can be determined by constructing 2 lines, the first being horizontal from the last point of zero slope and the second as a tangent to the strain hardening section of the curve, as close as possible to the point of inflection. The intersection between these 2 lines represents the end of yield point extension.*

As illustrated in Fig 14, the tangent to the strain hardening part of the curve is not well defined and a range of points and values can be chosen depending on the point at which strain hardening is deemed to start, and the algorithms used in the particular software to define this point. This difficulty is reflected in the values reported for A_e for this datafile, which range from 1.98% to 2.1%. Similar variability in A_e values was obtained for Files 15, 34, 36, 53 and 54.

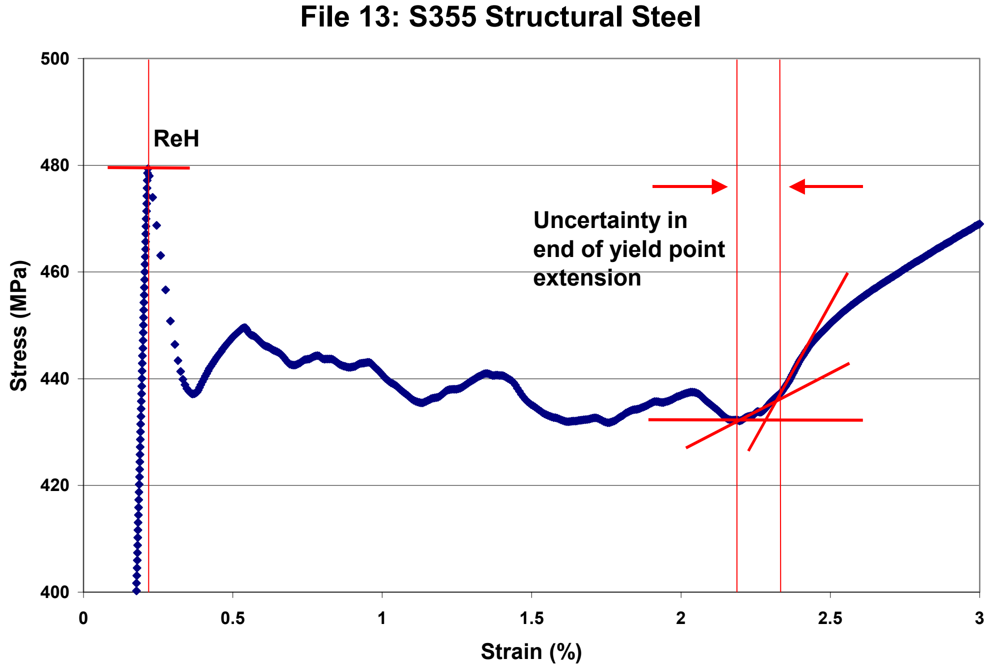


Fig 14: Example illustrating the difficulty in determining the yield point extension, A_e

The main difficulty in this case is how to define the start and end of plastic yielding. To reduce this uncertainty one approach would be to adopt the definition in Section 4.6.2 (and Fig 7) of ISO 6892 [3], which states that the **percentage yield point extension (A_e)** *in discontinuous yielding materials, is the extension between the start of yielding and the start of uniform work hardening.* Perhaps a more pragmatic approach could be to define A_e as the percentage extension between the points on the curve that define R_{eH} and R_{eL}.

It is recommended therefore that the Standards committee consider simplifying the definition and method for calculating A_e to reduce the large uncertainty in reported values.

7.5 EXAMPLE 5 – EFFECT OF MODULUS VARIATION ON OTHER PARAMETERS (FILES 22, 1, 6)

The uncertainty in modulus was the highest of all the parameters examined, and yet inspection of the ASCII datafiles and stress-strain curves do not show any files with significant non-linearity. Such large uncertainty should not be unexpected, as EN 10002-1 does not specifically cover the measurement or calculation of Young's modulus. However, the slope of the initial part of the curve is necessary for the calculation of proof strength values and the percentage non-proportional elongations at maximum force, A_g and percentage elongation after fracture, A (see Fig 1 in EN 10002-1 for schematic). More specific guidance on the measurement of the slope of the curve in the elastic range is given in Section A.4.9 in Annex A in the Standard.

A detailed assessment of the test methodology and analysis procedures for obtaining reliable modulus data from the tensile test has been carried out within TENSTAND WP3 [6], and is not reported in detail here. The main summary and recommendation from WP3 is that the test procedure currently described in EN 10002-1 is inadequate for accurate measurements of modulus, and that there is a real need for better guidance on modulus measurement and the techniques and algorithms used for calculating the slope of the curve, either via a separate Standard or as a new Annex to the current document. It is possible to get good quality modulus data from a tensile test, but this requires a separate test using high quality averaging strain measurement, focusing only on the early part of the stress-strain curve.

Within the tensile test itself, there are many practical difficulties associated with achieving a good straight portion of the curve, which corresponds to the modulus. For this reason some organisations select pre-determined or handbook values for the initial slope and modulus, which they then use to calculate the proof stress values. In this exercise, only one laboratory used default values for modulus (200 GPa for steel and 70 GPa for aluminium) in a complete set of analysis returns. Where these values are significantly different from the rest of the returns they have not been included in the statistics for the exercise.

The modulus of some materials is notoriously difficult to measure, but an accurate value is important for design purposes and for subsequent calculation of proof stress values and non-proportional elongation values in the full tensile test. The stress-strain curve below shows the typical effect different values for the slope can have on these parameters.

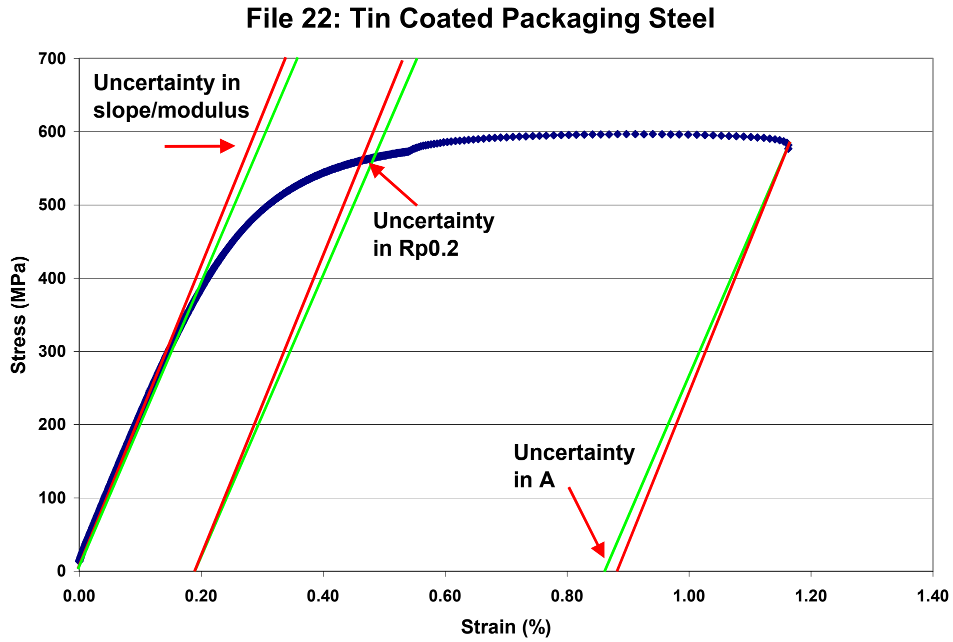


Fig 15: The influence of the variation in modulus on other parameters.

According to Sections 4.9.3 and 14.1 of EN 10002-1 the **Proof Strength ($R_{p0.1}$ and $R_{p0.2}$)** *is the stress at which a non-proportional extension is equal to a specified percentage of the extensometer gauge length. It is determined on the force-extension diagram by drawing a line parallel to the ordinate axis (force axis) and at a distance from this equivalent to the prescribed total percentage extension. The point at which this line intersects the curve gives the force corresponding to the desired proof strength, which is calculated by dividing this force by the original cross-sectional area of the testpiece.*

In Fig 15 above, two lines for the slope are shown, with values of 205 GPa and 199 GPa, both of which are within the range of values returned for the analysis of this datafile. It can be seen that the variation in modulus has an impact on the calculated values for R_p and A, with the agreed range of values for $R_{p0.2}$ being 560.5-563.0 MPa in this case. Although the differences in proof stress values are small (~ 0.5%) they might be expected to be greater for materials with significant work hardening since small variations in the modulus may result in large differences in the values of R_p. The corresponding values for $R_{p0.1}$ were 519.3-526.1 MPa, showing larger uncertainty as expected.

Section 13.1 of EN 10002-1 to some extent recognises the problems of measuring the slope at the beginning of the stress–strain curve, and offers the use of hysteresis loops and preloading as means of alleviating the problem. Although many tests showed small levels of preload, no hysteresis tests were carried out in generating the datafiles for this exercise.

Figures 16 and 17 show the stress-strain curves for Files 1 and 6 – the Nimonic 75 tensile reference material, which was the only material tested by both Zwick and Instron.

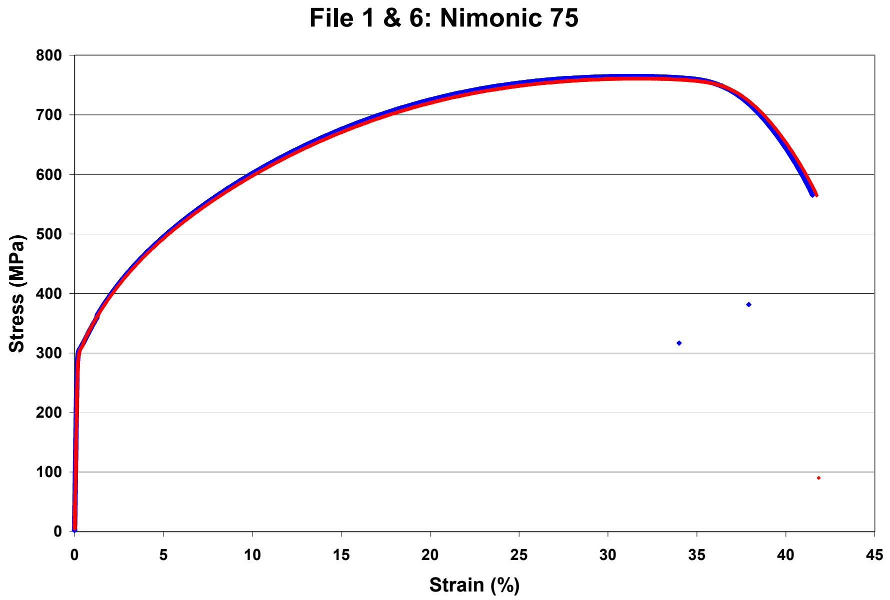


Fig 16: Comparison of stress-strain data for the Nimonic 75 reference material

The full stress-strain curves in Fig 16 show excellent agreement, and it would be expected that there would be generally only small differences in the modulus and proof stress values between the two datafiles. However, the expanded part of the stress-strain curves in Fig 17 show very different modulus values (mean values for E were 209.0 GPa and 188.3 GPa respectively for Files 1 and 6) and this has an effect on the calculated proof stress values. In this case, because the curve is relatively flat the variations are relatively small, but for other materials such differences could be significant.

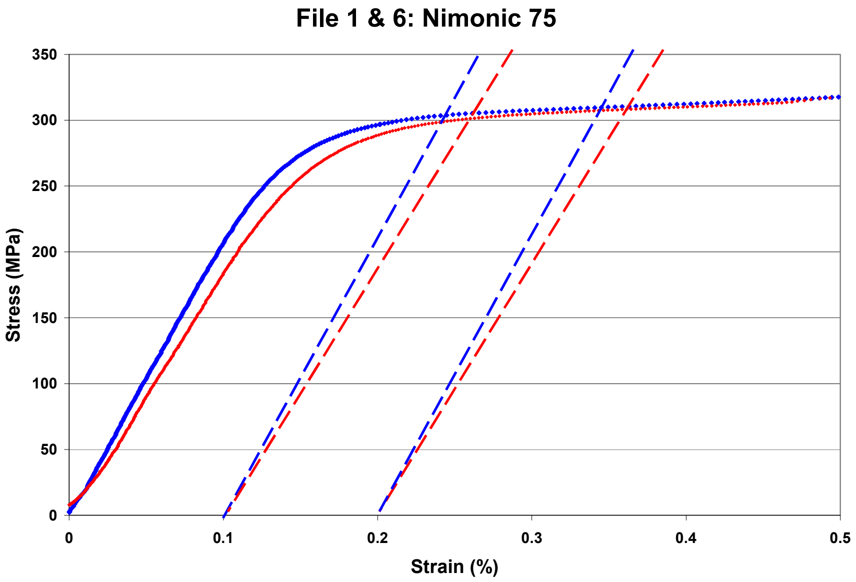


Fig 17: Expanded part of Fig 16 (above) showing the variation in modulus

The issue of modulus measurement is examined in greater detail in WP3. It is clear that the current procedure in EN 10002-1 is inadequate and **recommendations from WP3 include the use of a separate tensile test for determining modulus, using high precision averaging strain measurement, and testing over a limited strain range. The use of default handbook values for modulus is not recommended for absolute measurement of the properties, but can be adopted for comparison purposes or if the particular experimental set-up is not suitable for obtaining reliable modulus data. The use of default values must be reported.**

7.6 EXAMPLE 6 – CORRECTING FOR PRELOADS AND OFFSETS (FILE 42)

Many of the stress-strain curves generated in this exercise (see Files 22, 26, 30, 34, 42, 46, 50 and 53 in Fig 3) had a small preload applied to the specimen before testing. The effect of the preload is to effectively offset the start of the stress-strain curve and, if not taken into account, can introduce a significant error in the values calculated for R_p, A_g and A. Figure 18 below shows the potential effect on the calculation of $R_{p0.1}$ for File 42, which showed a high level of uncertainty in the analysis returns.

A note on preloads is given in Section 10.1 of the Standard, which states that ... *in order to obtain a straight testpiece and assure the alignment of the testpiece and grip arrangement, a preliminary force may be applied provided it does not exceed a value corresponding to 5% of the specified or expected yield strength. A correction of the extension should only be carried out to take into account the effect of the preliminary force.*

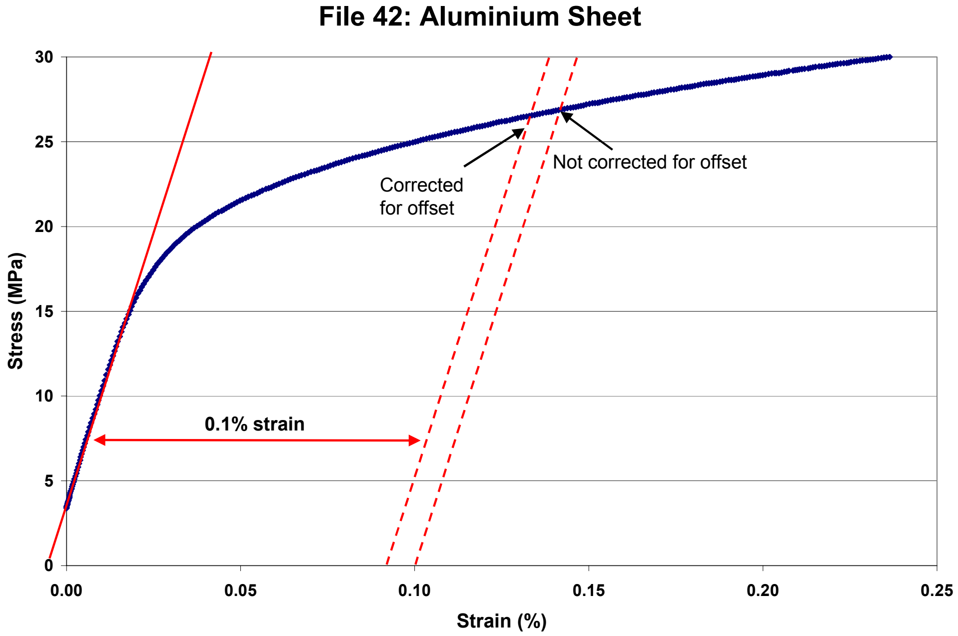


Fig 18: Example of curve with preload and offset.

At least 2 files (Files 42 and 50) had levels of preload higher than that recommended in the Standard, and it was clear that in many cases organisations did not follow the procedure for correcting for the offset. The only explicit mention of "the corrected origin to the curve" occurs in Section 13.1 of the Standard, which deals with the use of hysteresis testing to determine R_p. Note 2 states that ... *several methods can be used to define the origin of the force-extension curve. A method which may be used is to construct a line parallel to that determined by the hysteresis loop so that it is a tangent to the force-extension curve. The point where this line crosses the abscissa is the effective origin of the force-extension curve.*

The implication of not correcting for an offset at the origin can introduce significant errors in the calculation of material parameters, particularly for low strength and low elongation materials. The stress-strain curve for File 22, the tin coated packaging steel (Fig 15, shown previously) illustrates the problem. Due to a combination of factors, including the large variation in modulus reported for this datafile and several organisations not correcting for the offset, the range of values for "A" ranged from 0.83-0.89%.

Although the procedure for correcting for preloads and offsets is covered in the Standard, it is the recommendation that more explicit instructions are developed, including a Figure and example to illustrate the effect.

Note 2 in Section 17 of EN 10002-1 also states that elongation values should be rounded off to 0.5%, but it is questionable whether such rounding is sensible for low ductility materials (as seen in Files 22 (Fig15 above), Files 26 and 38), where small differences in elongation are significant and a higher level of precision is required, to reduce the errors and uncertainty in the values that would be introduced by rounding to the nearest 0.5%. Annex F of the Standard currently includes advice and information on measuring the percentage elongation after failure, but there is no comment on the precision of reporting the strain values.

In such cases, for example where 'A' is less than ~ 5%, it is recommended that the Standards committee consider changing the accuracy and rounding of strain readings reported to the nearest 0.1%.

7.7 EXAMPLE 7 – THE USE OF SYNTHETIC DATAFILES (FILE 57)

Figure 19 below shows the early part of a stress-strain curve from one of the synthetically generated files. A clear advantage of using mathematically generated data is that the stress-strain curve is free from the influence of test set-up and test machine software. It is also possible to tailor the curve with specific properties and more readily examine the sensitivity of software analyses to the effects of parameters such as noise. For the synthetic datafiles generated in this study (Files 57, 58, 61-64), in all cases the initial slope of the curve was selected to give a modulus value of 207.5 GPa. This was a perfect straight line between the stress values of 0-350 MPa, so it is a little disconcerting that two organisations returned values of 207.46 GPa and 206.69 GPa. Despite the request for strength and modulus values to be reported to one decimal place, some organisations applied rounding (both up and down!) so the uncertainty in modulus for this file (Table 7 and Fig 5) includes a contribution from this.

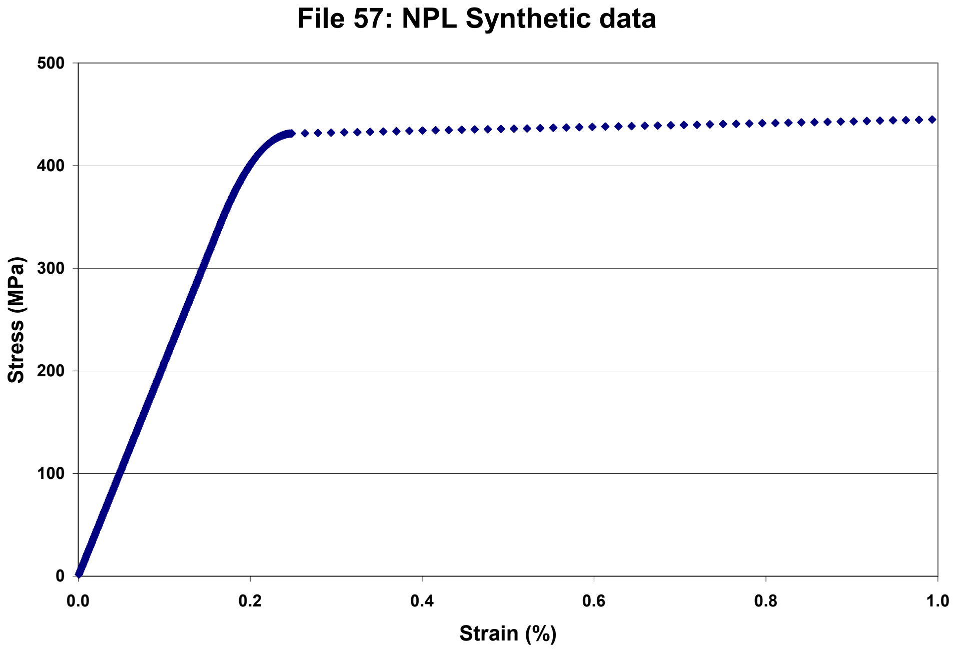


Fig 19. Synthetically generated curve with zero noise.

The effect of noise on the calculation of various parameters was examined using the set of synthetically generated stress-strain curves, which used the same force-extension data, with different levels of random noise applied to the force channel. For Files 61 and 62, 0.5% random noise was introduced on the force signal, and 1% noise for File 63 and 64. As can be clearly seen from Table 8 and Fig.5, the uncertainties generally increase with increasing levels of noise as might be expected.

7.8 EXAMPLE 8 – SCATTER IN IDENTIFYING FRACTURE POINT, A_T (FILE 30)

Several files showed a high degree of scatter in the value for $A_{t,}$ caused by different interpretations of when the testpiece had broken. The definition for the **percentage elongation at fracture (A_t)** is given in A.4.6 and states that … *the fracture is considered effective when the force between 2 measuring points decreases by more than 5 times the value of the previous 2 points followed by a decrease to lower than 3% of the maximum.*

An example is given in Fig 20 below, for the DX56 steel sheet (File 30). Even at a sampling rate of 50 Hz there were variations in the values reported, and in this example at least seven different points were identified with 'A_t'. Most organisations identified the point 'x6' as the fracture point where there was the specified decrease in force between the datapoints, and this was chosen as the agreed value, but there is considerable variation and uncertainty.

The reduction to 3% of the maximum force was not realised in this test (as was the case in many of the tests) as automatic data collection stopped as soon as specimen break was detected, or the data at the end of the test had been discarded. The situation is worse with lower sampling rates and fewer datapoints.

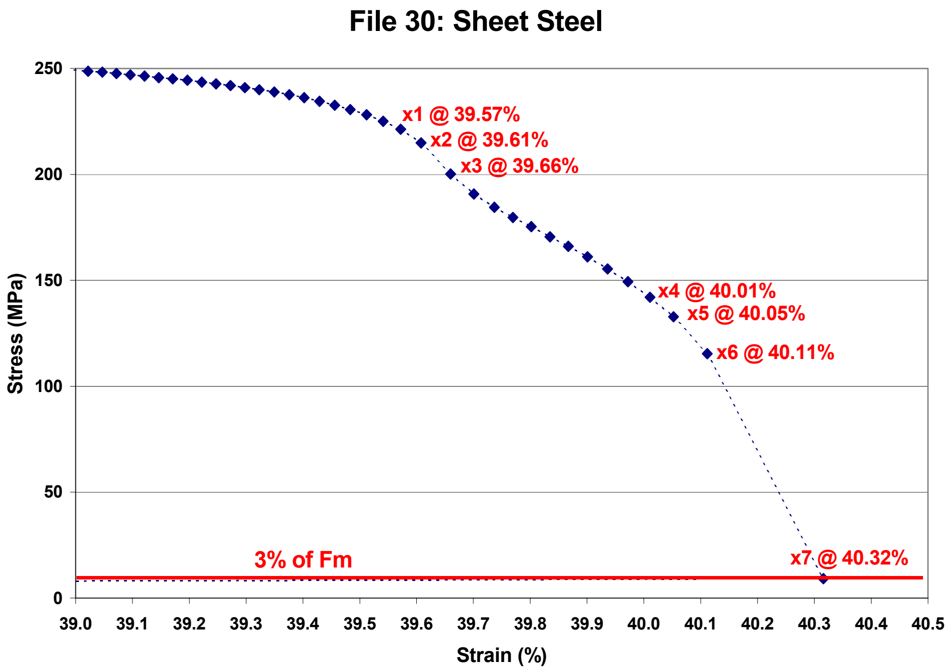


Fig 20. Curve illustrating the fracture point, and hence elongation at fracture, A_t

To reduce the uncertainty in detecting when testpiece fracture occurs, it is recommended that the definition for the fracture of the testpiece be reviewed, particularly with respect to the 3% force limit, as automatic data collection often stops before that point is reached and the value is not always reported.

7.9 EXAMPLE 9 – SMOOTHING AND NOISE (FILES 46, 61)

Figure 21 below shows the stress-strain curve for the soft AA5182 aluminium alloy (File 46), a material that exhibits serrated yielding. According to Section **4.4.2 and A.4.8** in Appendix A, the **percentage total elongation at maximum force (A_{gt})** *should be considered as the extension corresponding to the maximum of the stress-strain curve* ***reasonably smoothed after yield point phenomena.*** A note follows stating that a three-degree polynomial is recommended. Examination of Table 7 shows that the mean uncertainty values for A_{gt} is the second highest of all the parameters measured, and it is clear that smoothing has not been applied in most cases.

For the aluminium alloy datafile presented in Fig 21, the material suppliers confirmed that they would expect the data to be smoothed for calculating the values of A_g and A_{gt} and yet only 2 organisations did so. Also, as mentioned in Example 7, the effect of noise on the calculation of various parameters was examined using the synthetically generated stress-strain curves (Files 61-64). The uncertainties generally increase with increasing levels of noise as might be expected, but despite the appearance of the stress-strain curves, once again only two organisations applied smoothing to the data. Smoothing was applied to Files 10, 46, 61 and 63 and the percentage difference in calculated values between the smoothed and unsmoothed results are summarised in Table 8 below.

Table 8: Typical effect of smoothing on the results

	Percentage difference between smoothed and unsmoothed data		
	Rm	Ag	Agt
File 10 – 13%Mn Steel	0.7	1.3	1.3
File 46 – Soft Al sheet	1.6	5.3	5.2
File 61 – Synthetic + 0.5% noise	1.3	3.9	3.9
File 63 – Synthetic + 1% noise	2.7	1.5	1.5

Comparison of the values calculated with and without smoothing typically show differences of between 1-5%. It is interesting to note that the two organisations that used smoothing calculated different values for the parameters above. Also, it is not clear why the differences reported for A_g and A_{gt} should be lower for the synthetic file with 1% noise compared to the same data with 0.5% noise.

The issue of noise and smoothing has not been applied by participants in this study, and it is recommended therefore that the issue of smoothing the data be given further consideration and more visibility in future revisions of the Standard, with examples.

Because a definitive approach to smoothing the data cannot be given the agreed values for the ASCII datafiles have been selected prior to any further data processing and smoothing.

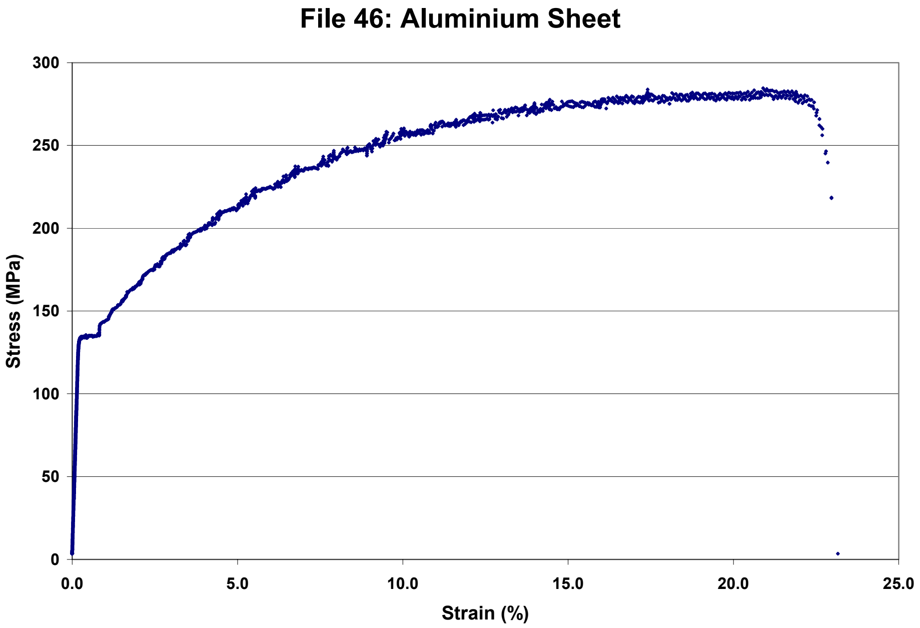


Fig 21: Stress-strain curve showing serrated yielding.

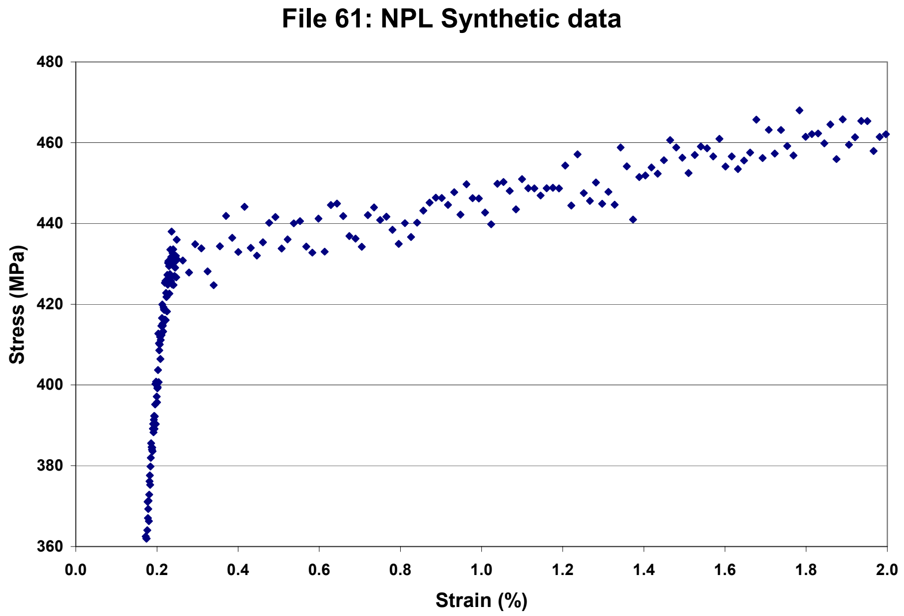


Fig 22: Synthetically generated curve with 0.5% noise.

7.10 EXAMPLE 10 – RELEVANCE OF FILES AT 5HZ SAMPLING RATE (FILES 44, 15)

As mentioned previously, all the tests for generating the ASCII datafiles used a data-sampling rate of 50Hz, but an important aspect of the exercise was to examine data that had been captured at lower sampling rates. Instead of carrying out an expensive set of repeat tests with a lower data sampling rate, a pragmatic approach was taken whereby the original datafiles were sampled to reduce the 50Hz data to an equivalent 5Hz test.

Section A.3.2 of the Standard gives recommendations on the minimum data sampling frequencies, which depend on the stress rate and value of R_{eH} or $R_{p0.2}$. There is a general requirement that the data sampling frequency should be sufficiently high to be able to record the material characteristics and parameters to be measured. It is clear from inspection of the 5Hz datafiles that this is not the case, and two examples are given in Figs 23 and 24 below. Figure 23 shows the stress-strain curve for the soft AA1050 aluminium sheet. In this case the main issues are the limited number of datapoints at the beginning of the curve (less than 10 datapoints cover the range over which the slope is calculated) and the reduced number of points available for defining the fracture point. (Consider also removing 9 out of 10 datapoints in File 30 (Fig 20) in example 8 above to see the effect). The part of the stress-strain curve presented in Figure 24 shows that the reduced number of datapoints leads to the loss of definition and resolution in the stress-strain curve, and there are problems detecting parameters such as R_{eH}, where there is a sharp change. Comparing values for R_{eH} for Files 13 (50Hz) and File 15 (5Hz) shows a reduction of 5 MPa (~1%) in the values reported, from data generated in the same test.

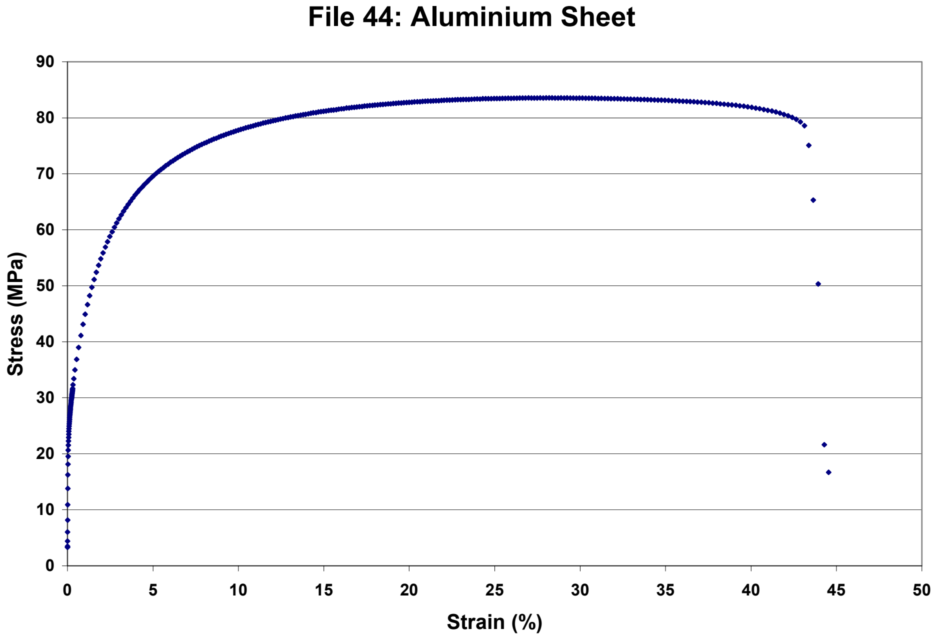


Fig 23: 5Hz datafile (File 44)

It is interesting to note also that the uncertainty values for the 5Hz data tend to be higher than the corresponding 50 Hz data. This is to be expected unless sophisticated data fitting and interpolation is used in the analysis software, because of the reduced number of datapoints and resolution of the actual material response.

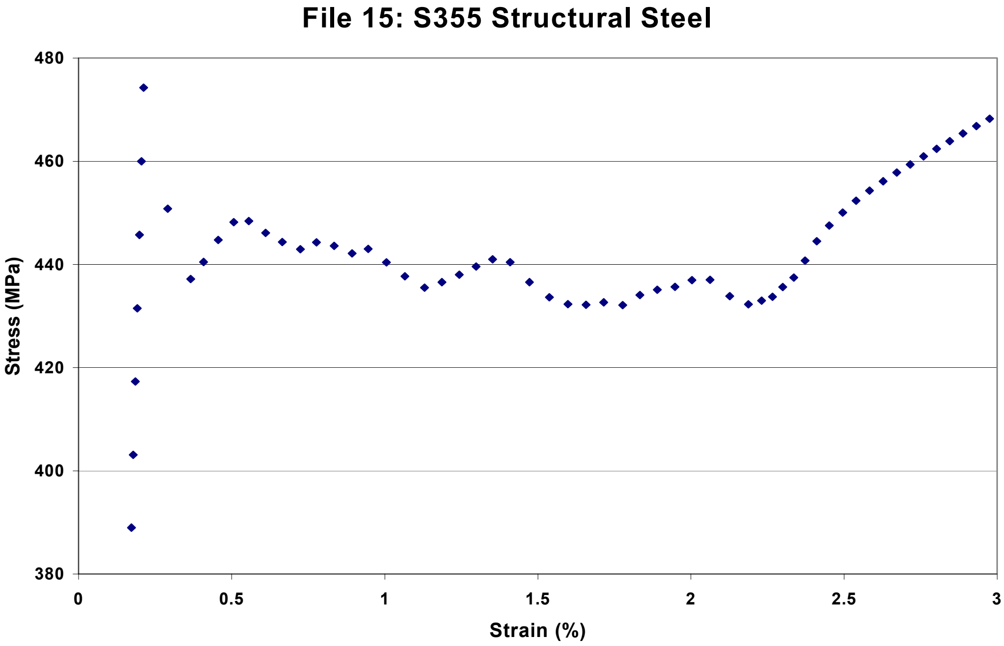


Fig 24: Example of the limited resolution in a 5Hz datafile (File 15)

Following detailed examination of all the 5Hz analysis returns and the stress-strain curves themselves, the recommendation of the WP2 working group was that the 5Hz datafiles would not be included in the Premium Quality datasets.

Further recommendations are that high data sampling rates are used, commensurate with the duration and test conditions. Consideration should be given to the practical aspects of handling the potentially large datafiles generated with the high sampling rates, and range of test rates and conditions being proposed in the Standard.

8 PREMIUM QUALITY ASCII DATASETS AND AGREED VALUES

Following detailed examination of the individual stress-strain curves and spreadsheet returns the WP2 working group reached agreement on a final set of datafiles, giving a range of material behaviour that could be used to validate the tensile test analysis software. Table 9 overleaf details the files and agreed values.

For the reasons described in the preceding section some datafiles have not been included, but the final Premium Quality Dataset of 15 datafiles includes at least one datafile from each material examined.

The TENSTAND WP2 Premium Quality Dataset is available for instrument manufacturers and operators to validate their tensile testing software both on CD and by downloading from the TENSTAND website at **www.npl.co.uk/npl/cmmt/projects/tenstand**

No 5Hz datafiles are included, but the full set of 64 datafiles generated as part of this study is available on request.

Table 9: Agreed values for the Premium Quality ASCII dataset (no smoothing applied)

Dataset	Material	Rp0.1 (MPa)	Rp0.2 (MPa)	ReH (MPa)	ReL (MPa)	Rm (MPa)	Fm (N)	A (%)	At (%)	Ag (%)	Agt (%)	Ae (%)	E (GPa)
1	Nimonic 75, CRM 661	303.4 - 304.5	309.6 - 310.1			764.4	59973	41.2	41.5	30.8	31.2		200.8 -216.5
6	Nimonic 75, CRM 661	300.5 - 301.8	308.0 - 308.6			761.1	59780	41.4	41.7	31.4	31.8		182.7 - 195.8
10	13%Mn Steel	334.5 - 334.9	337.1 - 337.2			937.0	72667	51.4	51.9	49.8	50.4		180.6 - 184.0
13	S355 Structural steel			479.4	431.8	567.2	44503	29.4	29.5	14.5	14.7	1.98 - 2.10	228.8 - 221.0
17	316L Stainless Steel	244.7 - 245.2	261.0 - 261.2			575.7	45278	51.1	51.3	38.3	38.6		189.8 - 202.3
22	Tin Coated packaging steel	525.6 - 530.6	562.5 - 564.6			596.7	2369	0.9	1.2	0.6	0.9		198.7 - 207.3
30	Sheet steel - DX56	157.2 - 157.6	162.7 - 162.9			301.5	4272	39.9 - 40.1	40.1	22.5	22.6		195.0 - 207.4
38	Aluminium Sheet - hard AA5182	385.2 - 386.8	396.4 - 397.1			434.3	2007	4.7	5.4	4.3	4.9		68.1 - 69.3
42	Aluminium Sheet - soft AA1050	26.48 - 26.55	30.01 - 30.05			83.6	1210	44.5	44.6	28.6	28.7		68.7 - 72.0
46	Aluminium Sheet -soft AA5182	133.4 - 133.9	134.5 - 134.8			284.6	8420	22.6 - 22.7	23.2	20.5	20.9		68.7 - 70.0
50	Sheet steel - DX56	158.6 - 158.7	163.9 - 164.0			303.9	2665	43.4 - 43.9	44.2	23.9	24.1		162.2 - 165.3
53	Sheet steel - ZStE			270.1	228.7	318.9	3782	40.3 - 40.8	40.8	18.9	19.1	1.74 - 1.80	198.7 - 208.9
57	Synthetic Digital Curve - zero noise	432.4	434.3			738.5	58000	50.0	50.2	39.6	40.0		207.5 - 208.0
61	Synthetic Digital Curve - 0.5% noise	431.8 - 434.1	438.1 - 441.6			748.1	58754	50.0	50.2	39.2	39.6		201.6 - 211.5
63	Synthetic Digital Curve - 1% noise	429.6 - 432.7	446.5 - 448.2			759.3	59632	50.0	50.2	37.3	37.7		203.0 - 211.6

9 VALIDATION OF SOFTWARE USING THE TENSTAND ASCII DATAFILES

Section A.5 of Appendix A in the Standard details a method for validating the software of the test machine. A procedure for comparing values calculated by the computer and those determined by examination of the stress-strain data is given, based on measuring and calculating the average value of the parameter of interest from tests on five testpieces.

This procedure only confirms the characteristics for the particular testpiece under specific test conditions, and inevitably will also include a contribution associated with the variation in the batch and the repeatability of the test itself. Table A.1 in Section A.5 gives the conditions for "proof of confidence" for $R_{p0.2}$, R_{p1}, R_{eH}, R_{eL}, R_m and A, based on the relative or absolute differences between the manual and computer-based measurements. Part of the table is reproduced below:

Table 9: Conditions for the proof of confidence (from Appendix A.5 of the Standard)

Parameter	**D, Mean difference between manual and computer evaluation**	
	Relative	**Absolute**
$\mathbf{R_{p0.2}}$	≤ 0.5%	2 MPa
$\mathbf{R_{p1}}$	≤ 0.5%	2 MPa
$\mathbf{R_{eH}}$	≤ 1%	4 MPa
$\mathbf{R_{eL}}$	≤ 0.5%	2 MPa
$\mathbf{R_m}$	≤ 0.5%	2 MPa
A		≤ 2%

If the differences measured from the validation exercise are smaller than the values given in Table 9 the software is deemed to be valid and appropriate for the test. The method above is somewhat unsatisfactory as the stress-strain curves generated as part of the five tests will invariably include some variation, but it does provide some validation of the data recording aspects of the test machine software. The approach is very conservative and it would be expected that modern test machine software should be able to measure a point such as the tensile strength, R_m to better than 2 MPa.

The use of default data files, such as the TENSTAND Premium Quality ASCII dataset generated within the WP2 activity in this project, should provide a more robust assessment of the software performance because the stress-strain curves have been thoroughly examined, and there is no factor due to material variability or test repeatability. Note 2 of Section A.5 confirms that pre-determined data from a known material with a *recognized level of quality assurance* can be used, but does not give further details. Table 10 below shows some of the results of the software validation exercise carried out in the current project, for all Laboratories and all the files in the TENSTAND Premium Quality ASCII dataset. The data presented is the difference between the values returned and the agreed mean values for R_m and $R_{p0.2}$. The colour coding of cells is the same as that used in the spreadsheet views, and helps to identify which Laboratories and datafiles had problems. In general the results show considerably lower variation than the values given in Table 9 above.

Although a manual procedure for validating the test machine software is prescribed in Annex A of the Standard, it is recommended that the Standards Committee consider introducing mandatory software validation using the TENSTAND Premium Quality ASCII datafiles.

Table 10: Difference between agreed & calculated values for Rm (top) and $Rp_{0.2}$ (bottom) for the ASCII Premium Quality Dataset

Tensile Strength, Rm

	TENSTAND ASCII Premium Datafile No.														
Lab No.	**1**	**6**	**10**	**13**	**17**	**22**	**30**	**38**	**42**	**46**	**50**	**53**	**57**	**61**	**63**
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-38.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	-0.1	-0.2	-7.0	0.0	0.0	-0.1	-0.2	0.0	-0.1	-2.9	-0.2	-0.2	0.0	-9.7	-18.9
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.3	0.0	0.1	0.0	0.3	0.3	-0.2	-0.9	0.0	-0.1	-0.1	-0.2	-0.3	-3.3	-4.9
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	-0.1	-0.1	-0.7	0.0	0.0	-0.5	-0.3	-6.3	-0.1	-3.8	-0.2	-0.3			
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-8.3	-18.8
13	-0.4	-0.1	0.0	-0.2	0.3	-0.7	-0.5	0.7	0.4	0.4	0.1	0.1	-0.5	-2.1	
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-675.5

0.2% Proof strength, Rp0.2

	TENSTAND ASCII Premium Datafile No.														
Lab No.	**1**	**6**	**10**	**13**	**17**	**22**	**30**	**38**	**42**	**46**	**50**	**53**	**57**	**61**	**63**
1	0.0	0.5	0.0		-0.1	0.6	-0.3	-0.1	0.0	0.0	-0.1		0.0	1.7	-17.6
2	0.0	0.0	0.0		1.1	0.0	0.0	-0.5	-0.1		0.0		0.1	2.6	-6.0
3	0.2	-0.6	-0.3		-1.9	-0.3	-0.1	-1.2	-0.2		-0.9		0.1	-7.5	0.5
4	-0.1	0.0	0.0		0.0	0.0	0.0	-0.2	0.0	0.0	0.0		0.0	0.8	0.3
5	-0.1	0.0	0.0		0.0	-1.0	-0.1	-0.2	0.1	0.0	-0.4		0.0	-2.6	0.4
6	-0.1	0.0	0.0		0.2	-0.6	0.0	-0.1	0.1	0.0	-0.2		0.0	1.0	-0.8
7	0.0	0.4	0.0		2.0	6.4	0.3	0.2	0.2	0.1	0.2		0.1	2.6	0.5
8	-0.2	0.0	0.3		2.3	0.7	0.2	0.0	1.3	-0.2	0.2		0.2	-0.3	0.0
9	-0.1	0.0	-0.2		0.1	0.7	0.1	-0.1	0.2		-0.1		0.0	-0.2	-3.2
10	-0.1	0.1	0.0		0.0	0.4	0.0	-0.1	0.0	0.1	0.0		0.0	0.6	0.2
11	0.1	0.3	0.0		-0.8	-1.5	-0.1	0.2	0.0	-0.1	0.0				
12	-0.1	-0.1	0.0		0.0	0.0	0.0	-0.1	0.0	0.1	0.0		0.0	-6.0	-12.7
13	0.1	-0.4	-0.2		0.1	-0.3	0.2	0.4	0.0	0.3	0.0		-0.3	0.5	
14	-0.1	0.1	0.0		0.1	0.9	0.0	0.2	0.1	-0.1	-0.1		0.0	1.1	0.1

10 CONTRIBUTION OF THE SOFTWARE TO THE MEASUREMENT UNCERTAINTY

Annex J in EN 10002-1 provides guidance on how to estimate the uncertainty in the measurements from the tensile tests, based on the approach in the ISO TAG4 document [7]. It is recognised that the precision of the test depends on a large number of factors including:

- Measurements of testpiece dimensions
- Measurement of force and extension
- Test temperature and loading rates
- Gripping system and the test machine characteristics and response
- Human and software errors
- Material inhomogeneity

Software errors are mentioned, but are not included in subsequent examples or calculations. Table J.1 in the Standard provides an estimate of the measurement uncertainty based on material independent parameters, and can be amended as proposed below, to include a contribution due to the software.

Table 11: Measurement Uncertainty based on material independent parameters, including the contribution due to software (Proposed modification of Table J.1 in the Standard)

Parameter	**Tensile properties, % error**						
	R_{eH}	**R_{eL}**	**R_m**	**R_p**	**A**	**z**	**E ****
Force	1	1	1	1			1
Strain				1	1		1
L_o				1	1		1
S_o	1	1	1	1		1	1
S_u						2	
Software *	1	0.5	0.5	0.5	1		3

* Taken from the values in Table A.1 in EN 10002-1

** Modulus, E, is not included in Table J.1 in EN 10002-1, but is an important parameter that has been examined in this study and within the separate activity in TENSTAND WP3

With the exception of the modulus 'E', the default values for the software contribution are taken from the maximum uncertainties given in Table 9 above (Table A.1 in the Standard). For the modulus contribution, a value has been selected based on the typical variation seen in the calculated modulus values for the WP2 exercise and from more detailed studies in TENSTAND WP3.

As mentioned above, it is recommended that mandatory software validation should be incorporated into the Standard, and carried out using the TENSTAND ASCII datafiles. A contribution due to the uncertainty associated with the software calculation should also be included in the uncertainty budget for the test and parameter being measured. Until the TENSTAND ASCII datafiles have been used to validate the software or the user can demonstrate otherwise, the default values for uncertainty currently proposed in Section A.5 in the Annex to the Standard should be used. It is recognized that these are probably somewhat over-conservative. Organizations are encouraged and recommended to use the Premium

Quality ASCII dataset to qualify the performance of their own software, following which the appropriate values for the uncertainty for the individual parameters can be substituted.

11 SUMMARY AND RECOMMENDATIONS TO STANDARDS COMMITTEE

The study carried out within WP2 of the TENSTAND project has produced a set of 15 reference ASCII datafiles for the verification of tensile test analysis software. To ensure further take up of this data and a common approach by the standards and material testing community it is recommended that …

- A procedure for the mandatory validation of tensile testing software should be included in the next revision of EN 10002-1, carried out using the TENSTAND Premium Quality ASCII datafiles.

- A common ASCII file format, in line with that developed within the TENSTAND project be adopted in the Standard

- A contribution due to the uncertainty associated with the software calculation should be included in the uncertainty budget for the test and parameter being measured.

- Until the TENSTAND ASCII datafiles have been used to validate the software, the default values for uncertainty currently proposed in Section A.5 in the Annex to the Standard be used. The default uncertainty values could be substituted by calculated values, based on the performance of the user's software and analysis of the ASCII Premium Dataset.

- The issue of modulus measurement should be examined further. Recommendations from WP3 include the use of a separate tensile test for determining modulus, using high precision averaging strain measurement, and testing over a limited strain range. The use of default handbook values for modulus is not recommended for absolute measurement of the properties, but can be adopted for comparison purposes or if the particular experimental set-up is not suitable for obtaining reliable modulus data. In all cases, the use of default values must be reported.

The software intercomparison exercise has shown that further clarification is required to remove uncertainty and ambiguity in the definition and calculations of some material parameters. From the examples presented in Section 7 of this report, it is recommended that the Standards committee consider and address the following changes:

- For materials that exhibit upper and lower yield phenomena, it is recommended that the test conditions be revised, either by not allowing a speed change until after R_{eL} has been reached, or by agreeing a set value of strain (e.g. 0.5%, 1% or 2%) at which this could be implemented.

- To reduce the uncertainty in detecting when testpiece fracture occurs, it is recommended that the definition for the fracture of the testpiece is reviewed, particularly with respect to the 3% force limit, as automatic data collection often stops before that point is reached and the value is not always reported.

For low elongation materials (e.g $A < 5\%$), consideration should be given to changing the accuracy and rounding of strain readings reported to the nearest 0.1%.

- To avoid ambiguities in the interpretation of the "initial transient effect", consideration should be given to expanding and clarifying the definition, with more realistic examples where appropriate.
- It is recommended also that the Standards committee consider simplifying the definition and method for calculating the percentage yield point extension 'A_e ' to reduce the large uncertainty in reported values.

And, to clarify the following areas, providing more instructive information where applicable to remove ambiguity in the interpretation, in particular …

- Clarifying the definition of F_m and R_m, particularly for materials that exhibit upper and lower yield phenomena where ambiguities may arise.
- That the issue of smoothing the data be given further consideration and more visibility in future revisions of the Standard, with examples.
- Although the procedure for correcting for preloads and offsets is covered in the Standard, it is recommended that more explicit instructions are developed, including a Figure and example to illustrate the effect.
- Further recommendations are that high data sampling rates are used, commensurate with the duration and test conditions. Consideration should be given to the practical aspects of handling the potentially large datafiles generated with the high sampling rates, and range of test rates and conditions being proposed in the Standard.

Until the issues have been resolved regarding the use of completely automated testing and analysis software for calculating tensile properties it is recommended that there should still be a manual check of the stress-strain data to ensure the correct values and parameters have been selected. This is probably not so much an issue in an industrial quality control laboratory, because they will be familiar with the particular material behaviour and should have set up the software accordingly. It is probably of greatest concern to those laboratories and organisations that test a variety of materials with different stress-strain behaviour.

At the time of writing this report, a number of the issues outlined above were raised with the Working Group, ISO TC164 SC1 WG4, charged with revising part of ISO 6892 relevant to Room Temperature Tensile Testing. The recommendations of the Working Group will be considered at the ISO meeting being held in Beijing, China in October 2004. It is the intention that a revised ISO 6892 will supersede EN10002-1 in due course, under the dual voting procedure of the Vienna Agreement.

12 ACKNOWLEDGEMENTS

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[2] EN 10002-Pt5: *Metallic Materials - Tensile Testing – Part 1: Method of Testing at elevated temperature*

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APPENDIX A GLOSSARY OF RELEVANT DEFINITIONS IN EN 10002-1

4.8 Maximum Force (F_m) …. is the greatest force which the testpiece withstands during the test **once the yield point has been passed**. For materials without yield point, it is the maximum value during the test

4.9.1 Tensile Strength (R_m) …. is the stress corresponding to the maximum force (F_m).

4.9.2.1 and **A.4.2 Upper yield strength (R_{eH})** .. is defined as the stress corresponding to the highest value of force prior to a reduction of at least 0.5% of the force and followed by a region in which the force should not exceed the previous maximum over a strain range not less than 0.05%

4.9.2.2 Lower yield strength (R_{eL}) …. is the lowest value of stress **during plastic yielding**, ignoring any transient effects. However in **A.4.3** it states that for productivity of testing a nominal value of R_{eL} may be reported as the lowest stress within the first 0.25% strain after R_{eH}, not taking into account any initial transient effect. When this procedure is used, it must be recorded in the test report. After determining R_{eL} by this procedure, the test rate may be increased as per 10.1.3. (This only applies to materials having yield phenomena and when A_e is not required).

4.9.3 and 14.1 Proof strength, non-proportional extension ($R_{p0.1}$ and $R_{p0.2}$) is the stress at which a non-proportional extension is equal to a specified percentage of the extensometer gauge length. It is determined on the force-extension diagram by drawing a line parallel to the ordinate axis (force axis) and at a distance from this equivalent to the prescribed total percentage extension. The point at which this line intersects the curve gives the force corresponding to the desired proof strength, which is calculated by dividing this force by the original cross-sectional area of the testpiece. **A.4.4** states that the values can be determined by interpolation between two points of the smoothed curve.

4.4.2 Percentage elongation after fracture (A) …permanent elongation of the gauge length after fracture, expressed as a percentage of the original gauge length

4.4.3 Percentage total elongation at fracture (A_t) .. is the total elongation (elastic plus plastic) of the gauge length at the moment of fracture. From A.4.6 … the fracture is considered effective when the force between 2 measuring points decreases by more than 5 times the value of the previous 2 points followed by a decrease to lower than 3% of the maximum

A_g is the **percentage non-proportional elongation at maximum force.**

4.4.2 and A.4.8 Percentage total elongation at maximum force (A_{gt}) should be considered as the extension corresponding to the maximum of the stress-strain curve, **reasonably smoothed after yield point phenomena.**

4.6.2 Percentage yield point extension (A_e) …. In discontinuous yielding materials, is the extension between the start of yielding and the start of uniform work hardening. A more detailed description is given in **A.4.7** whereby the method for determining A_e involves assessment of the two particular points in the force-extension curve which define the beginning and end of yield point extension. The beginning is that point where the slope becomes zero and is represented by a horizontal line. The end point can be determined by constructing two lines, the first being horizontal from the last point of zero slope and the second as a tangent to the strain hardening section of the curve as close as possible to the point of inflection. The intersection between these two lines represents the end of yield point extension.

Table A1: Full List of ASCII datafiles generated in WP2 (by Instron and Zwick)
(Files highlighted in green were selected for the intercomparison exercise)

TENSTAND :WP2: ASCII Data Set Files for Software Inter-Comparison

File No.	Material	Original File Name	Source	Data Capture Rate, Hz	Proof or Yield Stress
1	Nimonic 75, CRM 661	CRM 661-GBX 178-1	BCR/IRMM	50	P
2	Nimonic 75, CRM 661	CRM 661-GBX 178-2	BCR/IRMM	50	P
3	Nimonic 75, CRM 661	CRM 661-GBX 178-1	BCR/IRMM	5	P
4	Nimonic 75, CRM 661	CRM 661-GBX 178-2	BCR/IRMM	5	P
5	Nimonic 75, CRM 661	NPL-CRM661 No 8-1	BCR/IRMM	50	P
6	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	BCR/IRMM	50	P
7	Nimonic 75, CRM 661	NPL-CRM661 No 8-1	BCR/IRMM	5	P
8	Nimonic 75, CRM 661	NPL-CRM661 No 8-2	BCR/IRMM	5	P
9	13%Mn Steel	P1M 23-1	CORUS	50	P
10	13%Mn Steel	P1M 23-2	CORUS	50	P
11	13%Mn Steel	P1M 23-1	CORUS	5	P
12	13%Mn Steel	P1M 23-2	CORUS	5	P
13	S355 Structural steel	P1M 24-1	CORUS	50	Y
14	S355 Structural steel	P1M 24-2	CORUS	50	Y
15	S355 Structural steel	P1M 24-1	CORUS	5	Y
16	S355 Structural steel	P1M 24-2	CORUS	5	Y
17	316L Stainless Steel	S1C 20-1	CORUS	50	P
18	316L Stainless Steel	S1C 20-2	CORUS	50	P
19	316L Stainless Steel	S1C 20-1	CORUS	5	P
20	316L Stainless Steel	S1C 20-2	CORUS	5	P
21	Tin Coated packaging steel	SOLLAC F72-No7-1	SOLLAC	50	P
22	Tin Coated packaging steel	SOLLAC F72-No7-2	SOLLAC	50	P
23	Tin Coated packaging steel	SOLLAC F72-No7-1	SOLLAC	5	P
24	Tin Coated packaging steel	SOLLAC F72-No7-2	SOLLAC	5	P
25	Sheet steel	SOLLAC T462 No6-1	SOLLAC	50	Y
26	Sheet steel	SOLLAC T462 No6-2	SOLLAC	50	Y
27	Sheet steel	SOLLAC T462 No6-1	SOLLAC	5	Y
28	Sheet steel	SOLLAC T462 No6-2	SOLLAC	5	Y
29	Sheet steel	TKS-DX56 No 2-1	TKS	50	P
30	Sheet steel	TKS-DX56 No 2-2	TKS	50	P
31	Sheet steel	TKS-DX56 No 2-1	TKS	5	P
32	Sheet steel	TKS-DX56 No 2-2	TKS	5	P
33	Sheet steel	TKS-ZStE-180-No1-1	TKS	50	Y
34	Sheet steel	TKS-ZStE-180-No1-2	TKS	50	Y
35	Sheet steel	TKS-ZStE-180-No1-1	TKS	5	Y
36	Sheet steel	TKS-ZStE-180-No1-2	TKS	5	Y
37	Aluminium Sheet	VAW-hard AA5182-No3-1	VAW	50	P
38	Aluminium Sheet	VAW-hard AA5182-No3-2	VAW	50	P
39	Aluminium Sheet	VAW-hard AA5182-No3-1	VAW	5	P
40	Aluminium Sheet	VAW-hard AA5182-No3-2	VAW	5	P
41	Aluminium Sheet	VAW-soft AA1050 No 5-1	VAW	50	P
42	Aluminium Sheet	VAW-soft AA1050 No 5-2	VAW	50	P
43	Aluminium Sheet	VAW-soft AA1050 No 5-1	VAW	5	P
44	Aluminium Sheet	VAW-soft AA1050 No 5-2	VAW	5	P
45	Aluminium Sheet	VAW-soft AA5182 No 4-1	VAW	50	P
46	Aluminium Sheet	VAW-soft AA5182 No 4-2	VAW	50	P
47	Aluminium Sheet	VAW-soft AA5182 No 4-1	VAW	5	P
48	Aluminium Sheet	VAW-soft AA5182 No 4-2	VAW	5	P
49	Sheet steel	TKS-DX56-L050-B12-5-Probe 1	TKS	50	P
50	Sheet steel	TKS-DX56-L050-B12-5-Probe 2	TKS	50	P
51	Sheet steel	TKS-DX56-L050-B12-5-Probe 1	TKS	5	P
52	Sheet steel	TKS-DX56-L050-B12-5-Probe 2	TKS	5	P
53	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 1	TKS	50	Y
54	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 2	TKS	50	Y
55	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 1	TKS	5	Y
56	Sheet steel	TKS-ZStE-180-L050-B12-5-Probe 2	TKS	5	Y
57	Synthetic Digital Curve	NPL Zero Noise	NPL	50	P
58	Synthetic Digital Curve	NPL Zero Noise	NPL	5	P
61	Synthetic Digital Curve	NPL 0.5% Load Noise	NPL	50	P
62	Synthetic Digital Curve	NPL 0.5% Load Noise	NPL	5	P
63	Synthetic Digital Curve	NPL 1% Load Noise	NPL	50	P
64	Synthetic Digital Curve	NPL 1% Load Noise	NPL	5	P

Table A2: Examples of ASCII datafiles generated by Instron (top) and Zwick (bottom)

```
"Reference";"EN10002-1"
"Identification";"Tenstand"
"Material";"Nimonic"
"Extensometer to crosshead transition";0.00;"mm"
"Specimen geometry";"Circular"
"Cross-sectional area = So"
"Extensometer gauge length = Le"
"Extensometer output in mm"
"Parallel length = Lc"
"Data acquisition rate 50Hz"
"Data row for start force reduction (Hysteresis) = Hs"
"Data row for end force reduction (Hysteresis) = He"
"Data row for switch to crosshead = Cs"
"File length N data rows"
"File width M data columns"
"So";78.46129;"mm2"
"Le";50.00000;"mm"
"Lc";60.00000;"mm"
"N";3127
"M";4
"Hs";0
"He";0
"Cs";0
"time";"crosshead";"extensometer";"force"
"s";"mm";"mm";"kN"
0.00000;0.0515983300;0.0000579191;0.1913788000
```

```
"Reference";"DIN EN 10002-1"
"Identification";"Tenstand"
"Material";"CRM661 Nimonic 75"
"Extensometer to crosshead transition";0.00;"%"
"Specimen geometry";"round"
"Cross-sectional area = So"
"Extensometer gauge length = Le"
"Extensometer output in mm"
"Parallel length = Lc"
"Data acquisition rate 50Hz"
"Data row for start force reduction (Hysteresis) = Hs"
"Data row for end force reduction (Hysteresis) = He"
"Data row for switch to crosshead = Cs"
"File length N data rows"
"File width M data columns"
"So";78.54;"mm2"
"Le";50.00;"mm"
"Lc";60.00;"mm"
"N";3168
"M";4
"Hs";0
"He";0
"Cs";0
"time";"crosshead";"extensometer";"force"
"s";"mm";"mm";"kN"
0.01999;0.0000004712;0.0001500793;0.4039989013
```

Table A3: Details of analysis software used

Organisation	**Software used**
Zwick	TestXpert ver 10
NPL	In-house software (modification of modulus analysis software)
Instron	Merlin ver 5.41.00
Usinor/Sollac	In-house tensile analysis
Hydro Al	In-house EXCEL
MTS	MTS' TestWorks 4 monotonic application SW
BAM	In house software (using Excel; TechPlot)
Corus	Regraph ver 2
Dirlik	DC-Tensile
EMIC	Tesc ver 3.00

Table A4: Default sheet for analysis returns

TENSTAND: Tensile Testing Software Validation

Contact Details of Respondent:

Name:

e-mail:

Organisation:

Address:

Details of Software:

Title / Name:

Version:

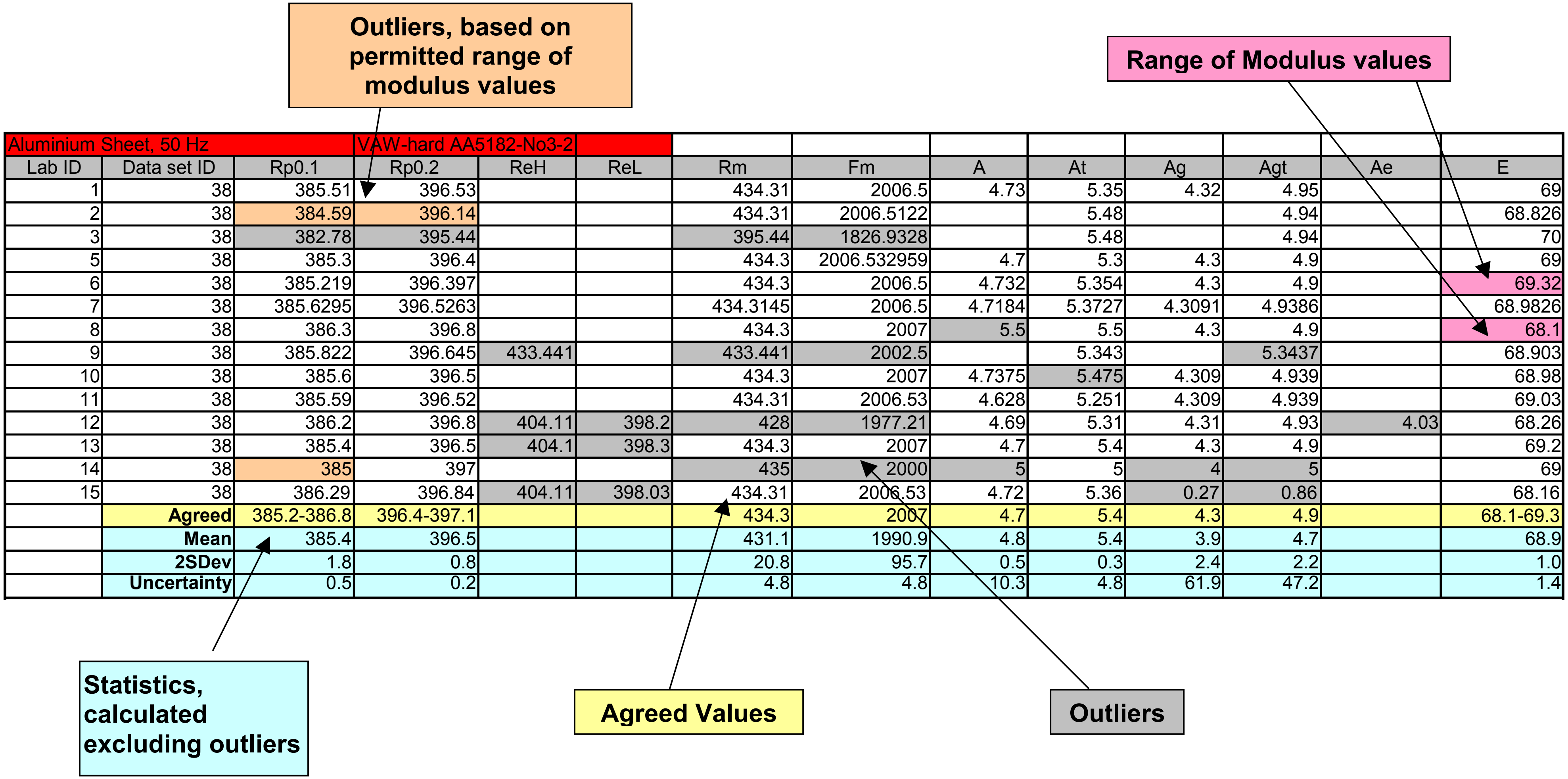
Year of issue :

Please insert your results in the appropriate columns

	Material	**Data Capture Rate Hz**	**$R_{p0.1}$** 0.10% Proof Stress **(MPa)**	**$R_{p0.2}$** 0.20% Proof Stress **(MPa)**	**R_{eH}** Upper Yield Stress **(MPa)**	**R_{eL}** Lower Yield Stress **(MPa)**	**R_m** Tensile Strength **(MPa)**	**F_m** Max. Force **(N)**	**A** Percentage Elongation at fract. **(%)**	**A_t** Elongation at Fracture **(%)**	**Ag** % Non-prop Elong at Fract. **(%)**	**Agt** % Total Elongation at fract. **(%)**	**A_e** Yield point extension **(%)**	**E** Young's Modulus **(GPa)**	**$A_{0.1}$** strain at $R_{p0.1}$ **(%)**	**$A_{0.2}$** strain at $R_{p0.2}$ **(%)**	**A_{eH}** strain at R_{eH} **(%)**
1	Nimonic 75, CRM661	50			X	X							X				X
3	Nimonic 75, CRM661	5			X	X							X				X
6	Nimonic 75, CRM661	50			X	X							X				X
8	Nimonic 75, CRM661	5			X	X							X				X
10	13% Mn Steel	50			X	X							X				X
12	13% Mn Steel	5			X	X							X				X
13	S355 Structural Steel	50	X	X											X	X	
15	S355 Structural Steel	5	X	X											X	X	
17	316L stainless Steel	50			X	X											X
19	316L stainless Steel	5			X	X											X
22	Tin coated steel, F721B	50			X	X							X				
24	Tin coated steel, F721B	5			X	X							X				
26	T462 Sheet steel	50	X	X													
28	T462 Sheet steel	5	X	X													
30	Steel DX56	50			X	X							X				
32	Steel DX56	5			X	X							X				
34	Steel Zste 180	50	X	X													
36	Steel Zste 180	5	X	X													
38	Hard Aluminium Sheet AA5182	50															
40	Hard Aluminium Sheet AA5183	5															
42	Aluminium AA1050	50			X	X							X				
44	Aluminium AA1050	5			X	X							X				
46	Soft Aluminium Sheet,AA5182	50			X	X							X				
48	Soft Aluminium Sheet,AA5182	5			X	X							X				
50	Sheet Steel TKS DX56	50			X	X							X				
52	Sheet Steel TKS DX57	5			X	X							X				
53	Sheet Steel TKS ZStE	50	X	X													
55	Sheet Steel TKS ZStE	5	X	X													
57	Synethic Curve Zero Noise	50			X	X							X				
58	Synethic Curve Zero Noise	5			X	X							X				
61	Synethic Curve 0.5% Noise	50			X	X							X				
62	Synethic Curve 0.5% Noise	5			X	X							X				
63	Synethic Curve 1% Noise	50			X	X							X				
64	Synethic Curve 1% Noise	5			X	X							X				

APPENDIX B SPREADSHEET OF ALL DATAFILES

Table B1: Key to spreadsheet view



Outliers, based on permitted range of modulus values

Range of Modulus values

Aluminium Sheet, 50 Hz			VAW-hard AA5182-No3-2										
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E
1	38	385.51	396.53			434.31	2006.5	4.73	5.35	4.32	4.95		69
2	38	384.59	396.14			434.31	2006.5122		5.48		4.94		68.826
3	38	382.78	395.44			395.44	1826.9328		5.48		4.94		70
5	38	385.3	396.4			434.3	2006.532959	4.7	5.3	4.3	4.9		69
6	38	385.219	396.397			434.3	2006.5	4.732	5.354	4.3	4.9		69.32
7	38	385.6295	396.5263			434.3145	2006.5	4.7184	5.3727	4.3091	4.9386		68.9826
8	38	386.3	396.8			434.3	2007	5.5	5.5	4.3	4.9		68.1
9	38	385.822	396.645	433.441		433.441	2002.5		5.343		5.3437		68.903
10	38	385.6	396.5			434.3	2007	4.7375	5.475	4.309	4.939		68.98
11	38	385.59	396.52			434.31	2006.53	4.628	5.251	4.309	4.939		69.03
12	38	386.2	396.8	404.11	398.2	428	1977.21	4.69	5.31	4.31	4.93	4.03	68.26
13	38	385.4	396.5	404.1	398.3	434.3	2007	4.7	5.4	4.3	4.9		69.2
14	38	385	397			435	2000	5	5	4	5		69
15	38	386.29	396.84	404.11	398.03	434.31	2006.53	4.72	5.36	0.27	0.86		68.16
	Agreed	385.2-386.8	396.4-397.1			434.3	2007	4.7	5.4	4.3	4.9		68.1-69.3
	Mean	385.4	396.5			431.1	1990.9	4.8	5.4	3.9	4.7		68.9
	2SDev	1.8	0.8			20.8	95.7	0.5	0.3	2.4	2.2		1.0
	Uncertainty	0.5	0.2			4.8	4.8	10.3	4.8	61.9	47.2		1.4

Statistics, calculated excluding outliers

Agreed Values

Outliers

Table B2: Summary of analysis returns

Nimonic 75, CRM 661, 50 Hz			CRM 661-GBX 178-1														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	1	303.99	309.87			764.36	59972.7	41.22	41.5	30.81	31.18		208	0.25	0.35		
2	1	303.84	309.88			764.36	59971.686		34	30.55	31.18		210.156	0.24	0.35		
3	1	304.57	310.1			764.36	59971.686		34	30.52	31.18		200	0.25	0.35		
4	1	303.8	309.8			764.4	59972.73	41.2	41.5	30.8	31.2		211	0.2	0.3		
5	1	303.8	309.768			764.4	59973	41.229	41.495	30.8	31.2		211.862	0.243	0.346		
6	1	303.8689	309.8033			764.3495	59971.9	41.2031	41.4726	30.9854	31.3489		210.3043	0.24516	0.34799		
7	1	304.2	309.9			764.4	59973	41.2	41.5	31.1	31.5		205.5	0.249	0.349		
8	1	304.927	309.706	764.708		764.708	60000		41.4		30.7		200.848	0.252	0.354	3.07	
9	1	303.9	309.8			764.4	59973	41.24	41.496	30.814	31.178		210.05	0.245	0.348		
10	1	303.86	309.8			764.36	59972.7	41.23	41.5	30.81	31.18		210.7	0.25	0.35		
11	1	304.2	310			764.3	59970.99	41.15	41.43	30.91	31.28		202.85	0.25	0.35		
12	1	303.9	309.8			764.4	59970	41.2	41.5	30.8	31.2		210.1	0.245	0.348		
13	1	303	310			764	59900	41	41.5	31	31.5		216.5	0.2	0.3		
14	1	303.94	309.84			764.36	59972.73	41.22	41.50	30.81	31.18		208.82				
	Agreed	303.5-304.6	309.6-310.2			764.4	59973	41.2	41.5	30.8	31.2		200.8-216.5	0.25	0.35		
	Mean	304.0	309.9			764.3	59972.2	41.2	41.5	30.8	31.2		209.0				
	2SDev	0.5	0.2			0.2	1.9	0.1	0.1	0.1	0.1		8.0				
	Uncertainty	0.1	0.1			0.0	0.0	0.3	0.2	0.4	0.2		3.9				

Nimonic 75, CRM 661, 5 Hz			CRM 661-GBX 178-1														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	3	303.9	309.88			764.35	59971.9	41.13	41.4	31.11	31.48		207	0.25	0.35		
2	3	304.22	311.37			764.35	59971.891		41.4	30.85	31.48		210.662	0.25	0.38		
3	3	307.1	311.37			764.35	59971.891		41.4	30.82	31.48		200	0.29	0.38		
4	3	303.7	309.8			764.4	59971.95	41.1	41.4	31.1	31.5		211	0.2	0.3		
5	3	303.649	309.797			764.4	59972	41.131	41.402	31.1	31.5		211.182	0.244	0.347		
6	3	303.7328	309.8254			764.3549	59972.3	41.1307	41.4028	30.9958	31.3599		209.8837	0.2453	0.3482		
7	3	304.2	309.2			764.4	59972	41.1	41.4	31.1	31.5		201.6	0.249	0.336		
8	3	303.971	310.662	764.708		764.708	60000		39.4		30.7		201.138	0.252	0.356	3.07	
9	3	303.7	311.3			764.4	59972	41.12	41.403	31.113	31.475		210.72	0.246	0.348		
10	3	303.55	309.76			764.35	59971.9	41.13	41.4	31.12	31.48		212.8	0.24	0.35		
11	3	304.2	310			764.3	59967.82	41.12	41.4	30.58	30.95		202.78	0.25	0.35		
12	3	303.8	309.8			764.4	59970	41.1	41.4	31.1	31.5		209.1	0.246	0.348		
13	3																
14	3	303.64	309.79			764.35	59971.95			31.09	31.48		211.24				
	Agreed	303.5-304.5	309.8-310.2			764.4	59972	41.1	41.4	31.1	31.5		201.1-212.8	0.25	0.35		
	Mean	303.9	309.8			764.4	59971.6	41.1	41.4	31.0	31.5		208.3				
	2SDev	0.5	0.2			0.1	2.5	0.0	0.0	0.2	0.1		8.3				
	Uncertainty	0.2	0.0			0.0	0.0	0.1	0.0	0.7	0.3		4.0				

Nimonic 75, CRM 661, 50 Hz			NPL-CRM661														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	6	302.3	308.89			761.14	59779.8	41.41	41.73	31.37	31.81		176	0.27	0.38		
2	6	301.25	308.36			761.14	59779.936		41.85	31.11	31.8		190.711	0.26	0.36		
3	6	300.31	307.84			761.14	59779.936		41.85	31.15	31.8		200	0.25	0.36		
4	6	301.3	308.4			761.1	59779.75	41.4	41.7	31.4	31.8		191	0.3	0.4		
5	6	301.414	308.403			761.1	59780	41.405	41.703	31.4	31.8		190.193	0.258	0.362		
6	6	301.4341	308.4104			760.9492	59764.9	41.4082	41.7066	31.2758	31.6766		189.8583	0.26195	0.36562		
7	6	301.9	308.8			761.1	59780	41.8	41.9	31.4	31.8		182.7	0.265	0.37		
8	6	301.757	308.441	761.077		761.077	59775		41.7		30.5		185.169	0.266	0.37	3.05	
9	6	301.5	308.4			761.1	59780	41.46	41.851	31.402	31.805		188.76	0.263	0.366		
10	6	301.65	308.48			761.14	59779.8	41.43	41.73	31.4	31.8		186.1	0.26	0.37		
11	6	301.9	308.7			761	59770.24	41.33	41.64	31.21	31.63		182.83	0.27	0.37		
12	6	301.1	308.3			761.1	59780	41.4	41.7	31.4	31.8		195.8	0.258	0.362		
13	6	301	308			761	59778	41.4	41.7	31.5	31.9		189	0.26	0.36		
14	6	301.57	308.46			761.14	59779.75			31.40	31.80		187.06				
	Agreed	300.7-302.0	308.2-308.8			761.1	59780	41.4	41.7	31.4	31.8		182.7-195.8	0.26	0.37		
	Mean	301.5	308.4			761.1	59778.6	41.4	41.8	31.3	31.7		188.3				
	2SDev	0.6	0.4			0.1	5.8	0.3	0.2	0.2	0.7		7.5				
	Uncertainty	0.2	0.1			0.0	0.0	0.6	0.4	0.7	2.2		4.0				

Table B2 (contd): Summary of analysis returns (contd)

Nimonic 75, CRM 661, 5 Hz			NPL-CRM661 No 8-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	8	302.26	308.82			761.08	59775	41.27	41.6	31.34	31.77		176	0.27	0.38		
2	8	302.94	308.36			761.08	59775.223		41.6	31.07	31.77		189.143	0.28	0.36		
3	8	302.94	308.36			761.08	59775.223		41.6	31.11	31.77		200	0.28	0.36		
4	8	301.2	308.4			761.1	59774.996	41.3	41.6	31.4	31.8		191	0.3	0.4		
5	8	301.328	308.428			761.1	59775	41.29	41.592	31.4	31.8		189.729	0.259	0.363		
6	8	301.3351	308.4312			760.9772	59767.2	41.2929	41.5956	31.171	31.5724		189.5922	0.26199	0.36573		
7	8	302.9	308.4			761.1	59775	41.3	41.6	31.4	31.8		182.3	0.276	0.364		
8	8	301.757	308.441	761.077		761.077	59775		39.65		30.65		184.992	0.268	0.37	3.065	
9	8	303	309			761	59775	41.24	41.596	31.366	31.769		188.76	0.262	0.366		
10	8	301.61	308.55			761.08	59775	41.28	41.6	31.36	31.77		184.7	0.26	0.37		
11	8	301.7	308.6			761	59767.87	41.28	41.6	30.83	31.24		183.59	0.27	0.37		
12	8	301	308.3			761.1	59770	41.3	41.6	31.4	31.8		194.5	0.259	0.363		
13	8																
14	8	301.33	308.43			761.08	59775.00			31.36	31.77		189.73				
	Agreed	300.6-301.9	308.1-308.7			761.1	59775	41.3	41.6	31.4	31.8		182.3-194.5	0.27	0.37		
	Mean	301.4	308.4			761.1	59775.0	41.3	41.4	31.3	31.8		188.0				
	2SDev	0.5	0.2			0.1	0.2	0.0	1.1	0.3	0.1		7.3				
	Uncertainty	0.2	0.1			0.0	0.0	0.1	2.7	0.8	0.4		3.9				

13%Mn Steel, 50 Hz			P1M 23-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	10	334.78	337.2			936.99	72666.5	51.42	51.92	49.84	50.36		181	0.28	0.39		
2	10	334.78	337.18			936.99	72666.676		52.53	49.19	50.36		180.574	0.28	0.39		
3	10	333.18	336.88			936.99	72666.676		52.53	49.3	50.36		200	0.26	0.37		
4	10	334.6	337.2			937	72666.5	51.4	51.9	49.8	50.4		184	0.3	0.4		
5	10	334.708	337.18			937	72666	51.427	51.915	49.8	51.915		182.642	0.283	0.385		
6	10	334.7537	337.1891			929.9645	72121.8	51.4114	51.9132	49.9423	50.4537		181.8515	0.2841	0.38543		
7	10	334.8	337.2			937	72667	52.2	52.5	49.8	50.4		181.5	0.284	0.385		
8	10	334.608	337.509	913.887		937.097	72675		51.76		50.32		182.514	0.286	0.388	4.632	
9	10	335	337			937	72667	51.48	52.527	49.848	50.358		183.88	0.282	0.384		
10	10	334.7	337.18			936.99	72666.5	51.2	51.71	49.84	50.36		183	0.28	0.39		
11	10	334.8	337.2			936.3	72616.65	51.39	51.9	49.82	50.34		181.65	0.28	0.39		
12	10	334.7	337.2			937	72670	51.4	51.9	49.8	50.4		183.1	0.283	0.385		
13	10	335	337			937	72667	51.5	52	50	50.5		183	0.28	0.38		
14	10	334.72	337.18			936.99	72666.50	51.42	51.92	43.79	44.28		182.53				
	Agreed	334.6-334.9	337.2			937.0	72667	51.4	51.9	49.8	50.4		180.6-184.0	0.28	0.39		
	Mean	334.8	337.2			937.0	72666.9	51.4	51.9	49.8	50.4		182.4				
	2SDev	0.2	0.1			0.1	2.1	0.2	0.4	0.4	0.1		2.1				
	Uncertainty	0.1	0.0			0.0	0.0	0.3	0.8	0.7	0.2		1.1				

13%Mn Steel, 5 Hz			P1M 23-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	12	334.64	337.26			935.22	72529.5	51.42	51.92	49.81	50.32		181	0.29	0.39		
2	12	335.65	337.65			935.22	72529.426		51.92	49.15	50.32		179.316	3	0.41		
3	12	335.65	337.65			935.22	72529.426		51.92	49.27	50.32		200	0.3	0.41		
4	12	334.5	337.2			935.2	72529.47	51.4	51.9	49.8	50.3		185	0.3	0.4		
5	12	334.579	337.242			935.2	72529	51.103	51.614	49.8	50.3		182.157	0.284	0.385		
6	12	334.6144	337.2516			932.803	72342	51.4238	51.9154	50.1342	50.6486		181.3524	0.28428	0.38573		
7	12	335.7	337.6			935.2	72529	51.4	51.9	49.8	50.3		181.6	0.299	0.406		
8	12	334.608	337.509	935.162		935.162	72525		51.6		50.32		183.63	0.286	0.388	5.032	
9	12	335.3	337.6			935.3	72529	51.48	51.915	49.814	50.324		183.49	0.284	0.384		
10	12	334.63	337.26			935.22	72529.5	51.1	51.61	49.81	50.32		181	0.28	0.39		
11	12	334.6	337.3			918.9	71263.21	51.42	51.92	47.3	47.8		181.59	0.28	0.39		
12	12	334.6	337.2			935.2	72530	51.3	51.8	49.8	50.3		182.5	0.284	0.385		
13	12																
14	12	334.60	337.25			935.22	72529.47			49.81	50.32		181.74				
	Agreed	334.3-334.8	337.2-337.3			935.2	72530	51.4	51.9	49.8	50.3		179.3-185.0	0.29	0.39		
	Mean	334.6	337.2			935.2	72529.0	51.3	51.8	49.7	50.3		182.0				
	2SDev	0.1	0.1			0.1	2.7	0.3	0.3	0.4	0.0		3.0				
	Uncertainty	0.0	0.0			0.0	0.0	0.6	0.5	0.7	0.0		1.6				

Table B2 (contd): Summary of analysis returns (contd)

S355 Structural steel, 50 Hz			P1M 24-1														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	13	448.42	439.13	479.36	431.79	567.19	44502.7	29.4	29.54	14.48	14.74	1.98	223	0.3	0.4	0.22	1.76
2	13			479.36	431.79	567.19	44502.462		35.27	14.41	14.74	2.04	228.849				
3	13			479.36	431.79	567.19	44502.462		35.27	14.36	14.74	2.04	200				
4	13			479.4	431.8	567.2	44502.68	29.4	29.5	14.5	14.7	2.1	223			0.2	1.8
5	13			479.356	431.791	567.2	44503	29.285	29.429	14.5	14.7	2.097	228.532			0.215	1.758
6	13			479.356	431.791	567.1718	44501	29.2863	29.4306	14.3143	14.5637	1.92112	227.41			0.21651	1.7598
7	13	446.4	439.4	479.4	431.8	567.2	44503	29.4	29.5	14.5	14.7	1.979	250.4	0.306	0.398	0.217	1.76
8	13	448.628	439.707	479.217		567.158	44500		29.4		13.52		224.182	0.3	0.396	0.2	
9	13			478.7	437.1	567.2	44503	29.42	29.535	14.483	14.737	2.13	223.11			0.214	0.368
10	13	447.86	439.36	479.36	431.79	567.19	44502.7	29.39	29.53	14.48	14.74	1.979	222.7	0.3	0.4	0.22	1.76
11	13			479.36	432.1	567.2	44501.44	29.2	29.35	14.34	14.59	2.88	220.97			0.22	2.2
12	13			479.4	431.8	567.2	44500	29.4	29.5	14.5	14.7		222.2			0.217	1.76
13	13			479	431	567	44500	29.5	29.5	14.5	14.5	2	226.8			0.2	2.2
14	13			479.36	431.79	567.19	44502.68			14.48	14.74		221.99				
	Agreed			479.36	431.79	567.2	44503	29.4	29.5	14.5	14.7	1.98-2.1	221.0-228.8			0.2	1.8
	Mean			479.3	431.8	567.2	44501.9	29.4	29.5	14.5	14.6		224.4				
	2SDev			0.2	0.0	0.1	2.4	0.2	0.1	0.1	0.6		5.5				
	Uncertainty			0.0	0.0	0.0	0.0	0.6	0.4	1.0	4.4		2.4				

S355 Structural steel, 5 Hz			P1M 24-1														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	15	449.29	439.48	474.27	432.09	567.19	44502.7	29.09	29.24	14.48	14.74	1.98	223	0.3	0.4	0.21	1.78
2	15			474.27	432.09	567.19	44502.462		35.27	14.42	14.74	1.9	233.79				
3	15			474.27	432.09	567.19	44502.462		35.27	14.36	14.74	1.9	200				
4	15			474.3	432.1	567.2	44502.68	29.1	29.2	14.5	14.7	2.2	223			0.2	1.8
5	15			474.273	432.091	567.2	44503	28.868	29.023	14.5	14.7	1.999	228.359			0.214	1.778
6	15			474.273	432.091	567.1783	44501.5	28.8667	29.0215	14.3603	14.6094	1.90917	227.7199			0.21232	1.77703
7	15	450.8	437.2	474.3	432.1	567.2	44503	29.1	29.2	14.5	14.7	1.975	221	0.291	0.366	0.212	1.777
8	15	448.628	439.707	474.119		567.158	44500		26.52		13.6		224.278	0.302	0.396	0.2	
9	15			474.2	437.1	567.2	44503	29.18	29.24	14.482	14.737	2.038	223.11			0.212	0.37
10	15	448.97	439.64	474.27	432.09	567.19	44502.7	29.09	29.24	14.48	14.74	1.975	222.9	0.3	0.4	0.21	1.78
11	15			474.27	432.1	567.2	44500.43	35.19	35.27	14.12	14.38	3.41	220.84			0.21	1.78
12	15			474.3	432.1	567.2	44500	29.1	29.2	14.5	14.7		219.2			0.212	1.777
13	15																
14	15			474.27	432.09	567.19	44502.68			14.48	14.74		221.59				
	Agreed			474.3	432.1	537.2	44503	29.1	29.2	14.5	14.7	2.0	219.2-228.3			0.2	1.8
	Mean			474.3	432.1	567.2	44502.0	29.0	29.2	14.5	14.6		224.1				
	2SDev			0.0	0.0	0.0	2.3	0.2	0.2	0.1	0.6		8.1				
	Uncertainty			0.0	0.0	0.0	0.0	0.8	0.6	0.8	4.4		3.6				

316L Stainless Steel, 50 Hz			S1C 20-1														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	17	244.41	260.83			575.72	45279.9	51.1	51.32	38.29	38.59		193	0.23	0.34		
2	17	246.44	261.98			575.72	45280.268		47.1	37.95	38.59		173.141	0.23	0.34		
3	17	240.34	259.04			575.72	45280.268		47.1	38.04	38.59		200	0.21	0.32		
4	17	244.5	260.9			575.7	45279.88	51.3	51.5	38.3	38.6		192	0.2	0.3		
5	17	244.475	260.865			575.7	45280	51.1	51.324	38.3	38.6		192.184	0.227	0.336		
6	17	244.8312	261.0695			575.6719	45276.5	51.0961	51.3223	38.2194	38.5227		189.7859	0.22743	0.33599		
7	17	247.1	262.9			575.7	45280	51.2	51.5	38.2	38.6		164.3	0.239	0.351		
8	17	247.298	263.191	575.97		575.97	45300		51.28		38.08		165.985	0.242	0.352	3.808	
9	17	244.7	261			575.7	45280	51.2	51.47	38.288	38.59		190.12	0.226	0.334		
10	17	244.47	260.86			575.72	45279.9	51.1	51.32	38.29	38.59		192.1	0.23	0.33		
11	17	247.7	260.1			575.7	45275.65	50.98	51.25	38.11	38.46		202.32	0.25	0.33		
12	17	244.5	260.9			575.7	45280	51.3	51.5	38.3	38.6		192	0.226	0.334		
13	17	245	261			576	45278	51.3	51.6	38.4	38.7		191.8	0.23	0.33		
14	17	244.79	261.05			575.72	45279.88			38.29	38.59		189.87				
	Agreed	242.7-244.9	259.9-261.1			575.7	452780	51.1	51.3	38.3	38.6		189.8-202.3	0.23	0.34		
	Mean	244.6	260.9			575.7	45279.2	51.2	51.4	38.3	38.6		193.2				
	2SDev	0.4	0.6			0.2	3.1	0.2	0.2	0.1	0.1		8.2				
	Uncertainty	0.2	0.2			0.0	0.0	0.4	0.5	0.3	0.2		4.3				

Table B2 (contd): Summary of analysis returns (contd)

316L Stainless Steel, 5Hz			S1C 20-1														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	19	243.51	260.73			575.67	45276.4	50.97	51.2	38.2	38.5		191	0.23	0.34		
2	19	247.9	263.37			575.67	45276.336		51.2	37.88	38.5		176.885	0.25	0.36		
3	19	247.9	263.37			575.67	45276.336		51.2	37.95	38.5		200	0.25	0.36		
4	19	243.6	260.8			575.7	45276.45	51	51.2	38.2	38.5		191	0.2	0.3		
5	19	243.514	260.736			575.7	45276	50.974	51.203	38.2	38.5		191.121	0.227	0.336		
6	19	243.7511	260.8933			575.6683	45276.2	50.9699	51.2015	38.2206	38.5248		189.2167	0.22716	0.33622		
7	19	247.9	263.4			575.7	45276	50.9	51.2	38.1	38.5		158.1	0.248	0.356		
8	19	246.663	262.556	575.97		575.97	45300		49.28		38.08		166.932	0.242	0.352	3.808	
9	19	245.8	262.2			575.7	45276	51.04	51.201	38.197	38.5		190.12	0.226	0.335		
10	19	243.3	260.59			575.67	45276.5	50.97	51.2	38.19	38.5		193.2	0.22	0.33		
11	19	247.3	260.1			575.7	45275.56	50.94	51.2	37.97	38.32		202.14	0.25	0.33		
12	19	243.5	260.7			575.7	45280	51	51.2	38.2	38.5		191.4	0.226	0.335		
13	19																
14	19	244.59	261.46			575.67	45276.45			38.19	38.50		181.37				
	Agreed	242.1-243.8	259.8-260.9			575.7	45276	51.0	51.2	38.2	38.5		190.12-202.1	0.24	0.34		
	Mean	243.7	260.8			575.7	45276.5	51.0	51.0	38.1	38.5		193.2				
	2SDev	0.8	0.7			0.0	2.3	0.1	1.1	0.2	0.2		9.2				
	Uncertainty	0.3	0.3			0.0	0.0	0.2	2.2	0.6	0.6		4.8				

Tin coated packaging steel, 50Hz			SOLLAC F72-No7-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	22	525.9	562.94			596.71	2368.9	0.88	1.17	0.61	0.91		199	0.36	0.48		
2	22	524.51	562.32			596.71	2368.9387		1.16	0.59	0.9		198.997	0.35	0.47		
3	22	523.55	561.99			596.71	2368.9387		1.16	0.59	0.9		200	0.35	0.47		
4	22	524.5	562.3			596.7	2368.9487	0.9	1.2	0.6	0.9		201	0.4	0.5		
5	22	521.584	561.288			596.7	2368.9	0.887	1.17	0.6	0.9		205.245	0.354	0.473		
6	22	522.6205	561.736			596.5859	2368.4	0.8673	1.1552	0.6201	0.9128		203.8441	0.34892	0.46811		
7	22	523.9	568.7			596.7	2369	0.83	1.16	0.55	0.9		171.2	0.351	0.508		
8	22	525.818	562.972	596.977		596.977	2370		1.155		8.9		200.558	0.355	0.474	0.89	
9	22	526.1	563			596.7	2369	0.8813	1.163	0.597	0.898		198.68	0.3563	0.475		
10	22	525.53	562.66			596.71	2368.95	0.8738	1.163	0.5984	0.8974		199.6	0.35	0.47		
11	22	541.8	560.8			596.2	2367.04	0.83	1.15	0.52	0.84		207.26	0.39	0.46		
12	22	524.5	562.3			596.7	2369	0.9	1.2	0.6	0.9		200.9	0.353	0.472		
13	22	522	562			596	2366	1	1	0.5	1		204	0.36	0.46		
14	22	526.59	563.16			596.71	2368.95			0.60	0.91		197.90				
	Agreed	519.3-526.1	560.5-563.0			596.7	2369	0.9	1.2	0.6	0.9		198.7-207.3	0.36	0.47		
	Mean	524.4	562.3			596.7	2369.0	0.9	1.2	0.6	0.9		201.3				
	2SDev	3.2	1.4			0.0	0.7	0.0	0.0	0.0	0.0		5.8				
	Uncertainty	0.6	0.3			0.0	0.0	2.5	2.8	1.4	1.1		2.9				

Tin Coated packaging steel, 5Hz			SOLLAC F72-No7-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	24	531.78	565.11			596.63	2368.6	0.87	1.17	0.64	0.95		190	0.38	0.5		
2	24	526.26	563.32			596.63	2368.6211		1.16	0.64	0.94		199.085	0.36	0.48		
3	24	526.26	563.32			596.63	2368.6211		1.16	0.64	0.94		200	0.36	0.48		
4	24	524.5	562.4			596.6	2368.6292	0.9	1.2	0.7	0.9		201	0.4	0.5		
5	24	521.779	561.393			596.6	2368.6	0.886	1.17	0.7	0.9		204.917	0.355	0.474		
6	24	522.4589	561.6346			596.632	2368.6	0.8778	1.1629	0.6482	0.9406		204.0549	0.34862	0.46782		
7	24	540.1	568.7			596.6	2369	0.82	1.16	0.59	0.94		170.5	0.389	0.508		
8	24	526.448	562.972	596.347		596.347	2367.5		0.94		0.873		200.449	0.3563	0.474	0.8725	
9	24	525.4	562.7			596.6	2369	0.8788	1.163	0.642	0.941		199.59	0.355	0.4738		
10	24	524.29	562.31			596.63	2368.63		1.163	0.644	0.9406		201.2	0.36	0.48		
11	24	541.5	569					0.85	1.16	0.02			170.3	0.39	0.51		
12	24	524.9	562.5			596.6	2369	0.8	1.1	0.7	0.9		200.4	0.354	0.472		
13	24																
14	24	527.92	563.68			596.63	2368.63						195.82				
	Agreed	521.3-533.2	561.2-565.6			596.6	2369	0.9	1.2	0.6	0.9		190.0-204.9	0.36	0.47		
	Mean	525.6	562.8			596.6	2368.7	0.9	1.2	0.6	0.9		199.7				
	2SDev	5.4	2.0			0.0	0.4	0.0	0.0	0.0	0.0		8.0				
	Uncertainty	1.0	0.4			0.0	0.0	1.5	0.7	1.0	4.4		4.0				

Table B2 (contd): Summary of analysis returns (contd)

Sheet steel, 50 Hz			SOLLAC T462 No6-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	26	511.78	511.82	556.73	504.91	512.11	2527.6	2.84	3.06	0.17	0.27	0.06	203	0.35	0.45	0.27	0.33
2	26			556.73	504.91	510.49	2317.6246		3.04	0.76	1.02	0.42	202.431				
3	26			553.73	504.91	510.49	2317.6246		3.04	0.76	1.02	0.42	200				
4	26			556.7	504.9	510.6	2318.1238	2.8	3.1	0.7	0.9	0.5	203			0.3	0.3
5	26			556.732	504.908	556.7	2527.6	2.84	3.059		0.269	0.084	206.29			0.269	0.329
6	26					556.5259	2526.6	2.8159	3.0493	-0.008	0.2656		203.4181				
7	26	511.8	511.8	556.7	504.9	512.1	2325	3.05	3.05	0.16	0.41	0.06	203.3	0.345	0.445	0.266	0.325
8	26	511.894	511.894	554.185		554.185	2516		30.47		3.047		201.458	0.3475	0.4475	0.2625	
9	26			556.6	504.4	556.7	2528	2.8375	3.055	-0.008	0.265	0.085	203.54			0.265	0.3225
10	26	511.79	511.7	556.59	504.91	512.11	2324.97	2.832	3.055	0.1596	0.4119	0.1257	203	0.35	0.45	0.27	0.325
11	26			556.73	505.7	549.3	2493.91	2.82	3.05	0	0.26		208.44			0.27	0.31
12	26			556.7	504.9	556.7	2528	2.8	3.1	0	0.3		203.1			0.266	0.325
13	26																
14	26			556.73	499.94	556.73	2527.56	2.84	3.06	0.25	0.50		204.12				
	Agreed			556.7	504.9	510.5	2325.0 or	2.8	3.1				201.5-208.4			0.27	0.33
	Mean			556.7	504.9	517.8	2444.5	2.8	3.1	0.3	0.7		203.8				
	2SDev			0.1	0.0	34.4	204.7	0.1	0.0	0.6	1.5		3.7				
	Uncertainty			0.0	0.0	6.6	8.4	5.1	1.3	193.9	223.0		1.8				

Sheet steel, 5Hz			SOLLAC T462 No6-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	28	511.44	511.83	556.2	505.01	511.94	2324.2	2.82	3.05	0.18	0.43	0.06	204	0.35	0.45	0.27	0.33
2	28			556.2	505.01	510.36	2317.0344		3.05	0.81	1.07	0.39	203.091				
3	28			556.2	505.01	510.36	2317.0344		3.05	0.81	1.07	0.39	200				
4	28			556.2	505	510.4	2317.3157	2.8	3	0.6	0.9	0.6	202			0.3	0.3
5	28			556.828	505.009	556.2	2155.2	2.817	3.05		0.27	0.084	205.637			0.27	0.329
6	28					550.6837	2500.1	2.8098	3.0457	-0.0061	0.2646		203.4435				
7	28	511.8	511.8	556.2	505	511.9	2324	2.81	3.05	0.17	0.42	0.059	203.3	0.345	0.445	0.265	0.325
8	28	511.894	511.894	551.541		551.541	2504		0.2625		0.2625		201.177	0.34875	0.44875	0.2625	
9	28			555.8	504.9	556.2	2525	2.825	3.046	-0.009	0.265	0.08625	203.04			0.265	0.3225
10	28	511.75	511.84	556.2	505.01	511.94	2324.2	2.783	3.023	0.1677	0.4195	0.0591	203.3	0.35	0.45	0.27	0.325
11	28			556.2	505	510.8	2319.04	2.82	3.05	0	0.24		202.54			0.27	0.32
12	28			556.2	505	556.2	2525	2.8	3	0	0.3		203.1			0.265	0.325
13	28																
14	28			556.2	505.01	556.20	2525.16			0.63	0.88		204.32				
	Agreed			556.2	505.0			2.8	3.1				201.2-205.6			0.27	0.33
	Mean			556.2	505.0	531.1	2382.9	2.8	2.8	0.4	0.5		203.2				
	2SDev			0.0	0.1	45.2	236.8	0.0	1.6	0.7	0.7		2.2				
	Uncertainty			0.0	0.0	8.5	9.9	0.9	57.1	179.1	125.6		1.1				

Sheet steel, 50 Hz			TKS-DX56 No 2-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	30	156.88	162.46			301.46	4271.7	39.95	40.01	22.46	22.6		224	0.17	0.27		
2	30	157.3	162.78			301.46	4271.6882		40.32	22.36	22.6		195.042	0.17	0.28		
3	30	157.12	162.66			301.46	4271.6882		40.32	22.37	22.6		200	0.17	0.27		
4	30	157.3	162.8			301.5	4271.6875	40.1	40.1	22.5	22.6		202	0.2	0.3		
5	30	157.295	162.748			301.5	4271.7	39.992	40.057	22.5	22.6		204.715	0.177	0.279		
6	30	157.3509	162.7984			301.3309	4269.9	39.4301	39.5411	22.5778	22.7265		202.6761	0.17292	0.27561		
7	30	158	163.1			301.5	4272	40.3	40.3	22.4	22.6		172.6	0.181	0.285		
8	30	158.08	163.02	301.34		301.34	4270		39.35		21.15		183.196	0.18	0.2825	21.15	
9	30	157.5	162.9			301.5	4272	40.125	40.316	22.442	22.596		195.75	0.175	0.2775		
10	30	157.35	162.8			301.46	4271.69	40.05	40.11	22.44	22.6		203.2	0.17	0.28		
11	30	158	162.7			301.2	4268.65	39.86	39.94	22.77	22.94		207.41	0.18	0.27		
12	30	157.4	162.8			301.5	4272	40.1	40.1	22.5	22.6		201	0.173	0.276		
13	30	157	163			301	4272	40.5	40.5	22.5	22.5		195	0.17	0.27		
14	30	157.40	162.84			301.46	4271.69			22.45	22.60		199.76				
	Agreed	157.2-157.6	162.7-162.9			301.5	4272	39.9-40.1	40.1	22.5	22.6		195-207.4	0.17	0.28		
	Mean	157.5	162.8			301.5	4271.8	40.1	40.2	22.4	22.6		200.6				
	2SDev	0.6	0.3			0.0	0.3	0.4	0.3	0.1	0.1		8.1				
	Uncertainty	0.4	0.2			0.0	0.0	0.9	0.9	0.5	0.3		4.0				

Table B2 (contd): Summary of analysis returns (contd)

Sheet steel, 5Hz			TKS-DX56 No 2-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	32	157.09	162.61			301.39	4270.7	39.29	39.41	22.15	22.29		210	0.17	0.28		
2	32	158.34	162.85			301.39	4270.6963		40.11	22.06	22.29		193.603	0.19	0.28		
3	32	157.12	162.85			301.39	4270.6963		40.11	22.06	22.29		200	0.17	0.28		
4	32	157.3	162.7			301.4	4270.688	40.1	40.1	22.1	22.3		201	0.2	0.3		
5	32	157.252	162.676			301.4	4270.7	39.291	39.407	22.1	22.3		204.109	0.177	0.28		
6	32	157.0911	162.6092			301.3267	4269.8	39.2898	39.4024	22.7824	22.9261		209.784	0.17052	0.27315		
7	32	158.3	162.8			301.4	4271	40	40.1	22.1	22.3		168.6	0.186	0.28		
8	32	157.727	163.02	301.34		301.34	4270		38.15		21		184.486	0.18	0.2825	21	
9	32	157.5	162.8			301.4	4271	40.125	40.112	22.133	22.29		191.23	0.1763	0.2788		
10	32	157.38	162.73			301.39	4270.69	39.64	39.74	22.13	22.29		198.4	0.18	0.28		
11	32	158	162.6			301.3	4269.13	40.05	40.11	22.66	22.83		205.85	0.18	0.27		
12	32	157.3	162.7			301.4	4271	39.3	39.4	22.1	22.3		200.9	0.173	0.276		
13	32																
14	32	157.35	162.72			301.39	4270.69	39.29	39.41	22.14	22.29		199.55				
	Agreed	157.3-157.6	162.6-162.8			301.4	4271	39.2-40.1	39.4	22.1	22.3		191.2-210.0	0.17	0.28		
	Mean	157.4	162.7			301.4	4270.7	39.6	39.7	22.2	22.3		201.3				
	2SDev	0.6	0.2			0.1	0.6	0.8	1.1	0.5	0.9		11.8				
	Uncertainty	0.4	0.1			0.0	0.0	2.0	2.8	2.2	4.0		5.9				

Sheet steel, 50 Hz			TKS-ZStE-180-No1-2			**Comment**											
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	34	243.26	244.19	270.18	236.69	318.23	6161	38.26	38.33	17.98	18.13	1.87	206	0.22	0.32	0.14	0.14
2	34			270.18	236.69	318.23	6160.9328		38.65	17.91	18.13	1.96	205.506				
3	34			270.18	236.69	318.23	6160.9328		38.65	17.91	18.13	1.96	200				
4	34			270.2	236.7	318.2	6160.9912	38.4	38.4	18	18.1	2.1	206			0.1	0.1
5	34			270.18	242.942	318.2	6161	38.377	38.436	18	18.1	2.045	209.936			0.136	0.679
6	34			270.18	240.38	318.1121	6158.6	37.6446	37.7596	18.1445	18.2984	2.01176	206.7021			0.13295	2.006
7	34	243.3	244.2	270.2	236.7	318.2	6161	38.6	38.7	18	18.1	1.985	206.8	0.213	0.313	0.133	0.137
8	34	243.285	244.059	263.429		318.052	6157.5		37.75		16.7		206.218	0.215	0.316	1	
9	34			270.1	237	318.2	6161	38.6625	38.651	17.976	18.129	0.08375	207.91			0.1325	0.13875
10	34	243.38	244.35	270.18	236.69	318.23	6160.99	28.49	38.53	17.98	18.13	1.873	206.7	0.22	0.32	0.13	0.137
11	34			270.18	236.7	318.2	6160.58	38.22	38.29	18.29	18.44	3.09	210.58			18.13	0.14
12	34			270.2	240.4	318.2	6161	38.4	38.4	18	18.1		206.5			0.133	2.006
13	34			270	241	318	6161	38.5	38.5	18	18	2.02	206.5			0.13	2.03
14	34			270.18	236.69	318.23	6160.99	38.38	38.44	17.98	18.13		205.94				
	Agreed			270.2	236.7	318.2	6161	38.2-38.5	38.65	18	18.1	1.87	205.5-210.6			0.13	0.14
	Mean			270.2	236.7	318.2	6161.0	38.4	38.4	18.0	18.1		206.5				
	2SDev			0.1	0.2	0.1	0.2	0.3	0.5	0.2	0.2		4.8				
	Uncertainty			0.0	0.1	0.0	0.0	0.8	1.3	1.1	1.2		2.3				

Sheet steel, 5Hz			TKS-ZStE-180-No1-2			**Comment**											
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	36	243.18	244.32	270	236.85	318.19	6160.1	37.56	37.68	18.93	19.08	1.87	206	0.22	0.32	0.14	0.14
2	36			270	236.85	318.19	6160.1584		38.37	18.86	19.08	1.87	206.573				
3	36			270	236.85	318.19	6160.1584		38.37	18.85	19.08	1.87	200				
4	36			270	236.8	318.2	6160.1309	37.6	37.7	18.9	19.1	2.1	206			0.1	0.1
5	36			270.003	242.919	318.2	6160	37.563	37.679	18.9	19.1	2.067	209.24			0.135	1.432
6	36			270.003	240.38	318.1119	6158.6	37.5588	37.6763	18.2742	18.4281	2.01401	206.7711			0.13205	2.006
7	36	243.2	244.7	270	236.8	318.2	6160	38.3	38.4	18.9	19.1	1.874	206.7	0.211	0.327	0.132	0.139
8	36	243.285	244.447	263.429		318.052	6157.5		36.4		16.35		206.246	0.2162	0.316	1	
9	36			270.1	237	318.2	6160	38.3625	38.369	18.924	19.078	0.08375	206.93			0.13125	0.13875
10	36	243.22	244.44	270	236.85	318.19	6160.13	37.92	38.01	18.92	19.08	1.874	206.5	0.22	0.32	0.13	0.139
11	36			270	236.8	318.2	6159.52	38.31	38.37	18.2	18.35	2.52	206.4			0.13	0.14
12	36			270	240.4	318.2	6160	37.6	37.7	18.9	19.1		207			0.132	2.006
13	36																
14	36			270	236.85	318.19	6160.13	37.56	37.68	18.93	19.08		206.96				
	Agreed			270.0		318.2	6160	37.6	38.4	18.9	19.1	1.87	206.0-209.2				
	Mean			270.0	236.9	318.2	6160.0	37.8	37.9	18.9	19.1		206.3				
	2SDev			0.1	0.1	0.0	0.4	0.7	1.1	0.1	0.0		4.1				
	Uncertainty			0.0	0.1	0.0	0.0	1.9	2.9	0.3	0.1		2.0				

Table B2 (contd): Summary of analysis returns (contd)

Aluminium Sheet, 50 Hz			VAW-hard AA5182-No3-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	38	385.51	396.53			434.31	2006.5	4.73	5.35	4.32	4.95		69	0.66	0.77		
2	38	384.59	396.14			434.31	2006.5122		5.48		4.94		68.826	0.65	0.76		
3	38	382.78	395.44			395.44	1826.9328		5.48		4.94		70	0.63	0.75		
4	38	385.3	396.4			434.3	2006.533	4.7	5.3	4.3	4.9		69	0.7	0.8		
5	38	385.219	396.397			434.3	2006.5	4.732	5.354	4.3	4.9		69.32	0.656	0.772		
6	38	385.6295	396.5263			434.3145	2006.5	4.7184	5.3727	4.3091	4.9386		68.9826	0.65209	0.76788		
7	38	386.3	396.8			434.3	2007	5.5	5.5	4.3	4.9		68.1	0.657	0.773		
8	38	385.822	396.645	433.441		433.441	2002.5		5.343		5.3437		68.903	0.654	0.77	4.9237	
9	38	385.6	396.5			434.3	2007	4.7375	5.475	4.309	4.939		68.98	0.6538	0.7688		
10	38	385.59	396.52			434.31	2006.53	4.628	5.251	4.309	4.939		69.03	0.66	0.78		
11	38	386.2	396.8	404.11	398.2	428	1977.21	4.69	5.31	4.31	4.93	4.03	68.26	0.66	0.77	0.85	0.86
12	38	385.4	396.5	404.1	398.3	434.3	2007	4.7	5.4	4.3	4.9		69.2	0.651	0.767	0.854	1.629
13	38	385	397			435	2000	5	5	4	5		69	0.6	0.7		
14	38	386.29	396.84	404.11	398.03	434.31	2006.53	4.72	5.36	0.27	0.86		68.16				
	Agreed	385.2-386.8	396.4-397.1			434.3	2007	4.7	5.4	4.3	4.9		68.1-69.3	0.66	0.77		
	Mean	385.7	396.6			434.3	2006.7	4.7	5.4	4.3	4.9		68.9				
	2SDev	0.8	0.4			0.0	0.5	0.1	0.3	0.0	0.0		1.0				
	Uncertainty	0.2	0.1			0.0	0.0	1.4	4.8	0.3	0.8		1.4				

Aluminium Sheet, 5 Hz			VAW-hard AA5182-No3-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	40	385.52	396.48			432.13	1996.4	4.7	5.32	4.32	4.94		69	0.66	0.77		
2	40	384.59	396.34			432.13	1996.4406		5.31	4.25	4.94		68.804	0.65	0.77		
3	40	382.98	395.57			432.13	1996.4406		5.31	4.26	4.94		70	0.63	0.75		
4	40	385.2	396.4			432.1	1996.4277	4.7	5.3	4.3	4.9		69	0.7	0.8		
5	40	385.217	396.38			432.1	1996.4	4.698	5.321	4.3	4.9		69.313	0.656	0.772		
6	40	385.6349	396.5204			432.1272	1996.4	4.6887	5.3141	4.3098	4.9362		68.9801	0.65211	0.76789		
7	40	386.2	396.7			432.1	1996	4.7	5.3	4.3	4.9		68.1	0.656	0.77		
8	40	385.281	396.536	432		432.034	1996		4.94		0.494		69.333	0.651	0.7675	4.9375	
9	40	385.7	396.5			432.1	1996	4.7	5.314	4.309	4.936		68.9	0.6525	0.7688		
10	40	385.49	396.47			432.13	1996.4	4.69	5.314	4.311	4.936		69.12	0.65	0.77		
11	40	386.3	396.8			399.2	1844.26	4.69	5.31	1.33	1.91		68.26	0.66	0.77		
12	40	385.6	396.5	400.7		432.1	1996	4.7	5.3	4.3	4.9		69	0.652	0.768	0.836	1.674
13	40	385	397										69	0.65	0.75		
14	40	386.42	396.85	400.66	398.03	432.13	1996.43						68.04				
	Agreed	385.2-386.8	396.4-397.1			432.1	1996	4.7	5.3	4.3	4.9		68.1-69.3	0.66	0.77		
	Mean	385.7	396.6			432.1	1996.3	4.7	5.3	4.3	4.9		68.9				
	2SDev	0.9	0.4			0.1	0.4	0.0	0.2	0.0	0.0		1.0				
	Uncertainty	0.2	0.1			0.0	0.0	0.2	4.1	1.1	0.8		1.5				

Aluminium Sheet, 50 Hz			VAW-soft AA1050 No 5-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	42	26.48	30.01			83.56	1210	43.83	43.91	28.56	28.68		72	0.14	0.24		
2	42	26.32	29.94			83.56	1209.9488		44.55	28.45	28.67		63.244	0.13	0.23		
3	42	26.17	29.82			83.56	1209.9488		44.55	28.48	28.67		70	0.12	0.23		
4	42	26.5	30			83.6	1209.9811	44.5	44.5	28.6	28.7		70	0.1	0.2		
5	42	26.607	30.107			83.6	1210	44.472	44.499	28.6	28.7		66.197	0.14	0.245		
6	42	26.627	30.1215			83.5474	1209.8	43.2319	43.3485	28.1008	28.2282		65.5887	0.1352	0.24053		
7	42	26.7	30.2			83.6	1210	44.5	44.5	28.5	28.7		61.1	0.138	0.243		
8	42	28.14	31.33	83.563		83.56	1210		44.05		26.45			0.17625	0.289	26.45	
9	42	26.68	30.19			83.91	1210	44.6	44.546	28.55	28.673		68.67	0.1338	0.2388		
10	42	26.51	30.04			83.562	1209.98	43.86	43.94	28.55	28.67		70.17	0.14	0.24		
11	42	31	30			83.5	1209.6	44.4	44.44	27.49	28.25		71.92	0.28	0.24		
12	42	26.5	30			83.6	1210	44.5	44.6	28.6	28.7		69.8	0.133	0.238		
13	42	26	30			84	1210	44.5	44.5	29	29.5		71	0.13	0.23		
14	42	26.63	30.12			83.56	1209.98	43.87	43.94	28.56	28.68		65.22				
	Agreed	26.48-26.55	30.01-30.05			83.6	1210	44.5	44.6	28.6	28.7		68.7-72.0	0.14	0.24		
	Mean	26.5	30.0			83.6	1209.9	44.5	44.5	28.5	28.7		69.9				
	2SDev	0.0	0.0			0.1	0.2	0.1	0.3	0.1	0.0		4.1				
	Uncertainty	0.1	0.1			0.1	0.0	0.3	0.7	0.4	0.1		5.8				

Table B2 (contd): Summary of analysis returns (contd)

Aluminium Sheet, 5 Hz			VAW-soft AA1050 No 5-2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	44	26.5	30.01			83.56	1210	43.28	43.38	28.77	28.89		72	0.14	0.24		
2	44	26.44	30.08			83.56	1209.9488		44.55	28.65	28.88		60.15	0.13	0.24		
3	44	26.44	29.86			83.56	1209.9488		44.55	28.69	28.88		70	0.13	0.23		
4	44	26.5	30			83.6	1209.9622	44.5	44.5	28.8	28.9		70	0.1	0.2		
5	44	26.553	30.055			83.6	1210	43.274	43.383	28.8	28.9		68.953	0.139	0.244		
6	44	26.601	30.094			83.5472	1209.8	43.0089	43.1269	27.9198	28.0453		66.554	0.13468	0.23993		
7	44	26.8	30.3			83.6	1210	44.5	44.5	28.7	28.9		60.1	0.138	0.247		
8	44	28.14	31.33	83.563		83.56	1210		42.9		26.4			0.175	0.2875	26.4	
9	44	26.5	30.01			83.56	1210	44.6	44.546	28.768	28.885		71.82	0.1325	0.2375		
10	44	26.56	30.08			83.561	1209.96	43.86	43.94	28.76	28.88		67.07	0.14	0.25		
11	44	31.3	30.1			83.6	1210	44.53	44.55	27.38	28.18		66.97	0.29	0.24		
12	44	26.6	30.1			83.6	1210	43.9	43.9	28.8	28.9		66.2	0.135	0.24		
13	44																
14	44	26.62	30.11			83.56	1209.96	43.56	43.65	28.77	28.89		65.51				
	Agreed	26.49-26.61	30.00-30.10			83.6	1210		43.38	28.8	28.9		66.2-72.0	0.14	0.24		
	Mean	26.6	30.1			83.6	1210.0	43.9	44.0	28.8	28.9		68.5				
	2SDev	0.1	0.1			0.0	0.1	1.2	1.2	0.1	0.0		4.7				
	Uncertainty	0.4	0.3			0.0	0.0	2.8	2.8	0.4	0.1		6.9				
Aluminium Sheet, 50 Hz			VAW-soft AA5182 No 4-2			**Comment**				Need to apply smoothing for Ag and Agt only							
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	46	133.56	134.66	134.4	133.8	284.56	8420.3	22.65	22.97	20.49	20.9	0.55	69	0.29	0.39	0.27	0.44
2	46			142.16	142.16	284.56	8420.1304		23.16	20.29	20.9		68.152				
3	46			142.16	142.16	284.56	8420.1304		23.16	20.3	20.9		70				
4	46	133.5	134.7			284.6	8420.2715	22.7	23	20.5	20.9		69	0.3	0.4		
5	46	133.507	134.7			284.6	8420.3	22.436	22.788	20.5	20.9		69.614	0.292	0.393		
6	46	133.545	134.6632			281.6558	8334.2	22.6445	22.9604	20.8264	21.2336		69.1678	0.28751	0.38912		
7	46	133.7	134.8			284.6	8420	23.2	23.2	20.5	20.9		68.9	0.289	0.388		
8	46	133.82	134.5	220.682		284.55	8420		22.95		20.9		69.085	0.289	0.39	5.25	
9	46			134.5	133.4	284.6	8420	22.6625	22.964	20.484	20.897	0.63	68.91			0.26875	0.285
10	46	133.45	134.76			284.56	8420.27	22.65	22.96	20.49	20.9		69.5	0.29	0.39		
11	46	133.6	134.6			280.8	8308.21	22.45	22.8	20.59	20.99		70.02	0.29	0.39		
12	46	133.4	134.8			284.6	8420	22.7	23	20.5	20.9		69.5	0.286	0.388		
13	46	134	135			285	8420	23.1	23.2	20.5	20.9		68.7	0.29	0.39		
14	46	133.58	134.65			284.56	8420.27			0.23	0.42		69.04				
	Agreed	133.4-133.9	134.5-134.8			284.6	8420	22.6-22.7	23.16	20.5	20.9		68.7-70.0	0.29	0.39		
	Mean	133.6	134.7			284.6	8420.1	22.7	23.0	20.5	20.9		69.3				
	2SDev	0.3	0.3			0.2	0.3	0.1	0.3	0.2	0.1		0.8				
	Uncertainty	0.3	0.2			0.1	0.0	0.2	1.2	0.9	0.2		1.2				
Aluminium Sheet, 5 Hz			VAW-soft AA5182 No 4-2							Need to apply smoothing for Ag and Agt only							
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	48	134.4	134.73	135.41	134.12	282.87	8370.2	22.12	22.51	20.57	20.98		69	0.29	0.39	0.42	0.46
2	48			143.23	143.23	282.87	8370.1233		22.86	20.37	20.97		68.043				
3	48			143.23	143.23	282.87	8370.1233		22.86	20.38	20.97		70				
4	48	134.4	134.7			282.9	8370.1768	22.5	22.9	20.6	21		69	0.3	0.4		
5	48	134.375	134.761			282.9	8370.177	21.831	22.229	20.6	21		69.538	0.293	0.394		
6	48	134.4019	134.7324			282.8718	8370.2	22.5092	22.8555	20.563	20.9718		69.1811	0.28874	0.38921		
7	48	134.5	134.8			282.9	8370	22.5	22.9	20.6	21		68.9	0.293	0.388		
8	48	134.504	134.842	257.857		282.86	8370		21.975		20.975		68.772	0.29125	0.39125	9.525	
9	48			134.6	133.6	282.9	8370	22.5125	22.854	20.561	20.97	0.6225	69.03			0.265	0.2775
10	48	134.4	134.73			282.87	8370.18	22.12	22.5	20.56	20.97		69.06	0.29	0.39		
11	48	134.4	134.8			277.7	8218.34	22.51	22.86	16.86	17.26		69.57	0.29	0.39		
12	48	134.4	134.7			282.9	8370	21.8	22.2	20.6	21		69.6	0.288	0.388		
13	48																
14	48	134.41	134.73			282.87	8370.18			7.56	7.91		69.01				
	Agreed	134.4-134.5	134.6-134.8			282.9	8370	22.5	22.9	20.6	21.0		68.0-69.6	0.29	0.39		
	Mean	134.4	134.7			282.9	8370.1	22.5	22.9	20.5	21.0		69.1				
	2SDev	0.1	0.1			0.0	0.2	0.0	0.0	0.2	0.0		1.0				
	Uncertainty	0.1	0.1			0.0	0.0	0.1	0.2	0.9	0.1		1.4				

Table B2 (contd): Summary of analysis returns (contd)

Sheet steel, 50 Hz			TKS-DX56-L050-B12-5-Probe 2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	50	159.04	163.87			303.88	2665	43.47	43.59	23.94	24.14		155	0.2	0.31		
2	50	158.56	163.98			303.88	2665.0276		44.17	23.84	24.13		163.634	0.19	0.29		
3	50	156.92	163.07			303.88	2665.0276		44.17	23.89	24.13		200	0.17	0.27		
4	50	158.6	164			303.9	2664.9885	43.9	43.9	23.95	24.1		165	0.2	0.3		
5	50	156.513	163.618			303.9	2665	44.121	44.125	24	24.1		177.772	0.189	0.292		
6	50	158.5616	163.8241			303.7227	2663.6	43.325	43.4462	23.9559	24.1305		174.016	0.1836	0.28662		
7	50	158.5	164.2			303.9	2665	44.2	44.2	23.9	24.1		144.8	0.182	0.298		
8	50	159.635	164.196	303.762		303.76	2664		43.4		21.7		149.231	0.196	0.3	21.7	
9	50	158.7	163.9			303.9	2665	44.2	44.171	23.938	24.125		162.23	0.188	0.292		
10	50	158.61	163.96			303.88	2664.99	43.87	43.92	23.94	24.13		165.5	0.2	0.3		
11	50	159.4	164			303.7	2663.36	43.72	43.8	23.98	24.18		166.46	0.2	0.29		
12	50	158.6	164			303.9	2665	43.9	43.9	24	24.1		170	0.184	0.288		
13	50	159	164			304	2700	44	44.1	24	24.1		164	0.19	0.29		
14	50	158.77	163.88			303.88	2664.99	43.53	43.66	23.91	24.15		160.39				
	Agreed	158.6-158.7	163.9-164.0			303.9	2665	43.4-43.9	44.17	23.9	24.1		162.2-165.3	0.19	0.3		
	Mean	158.7	164.0			303.9	2665.0	43.8	43.9	23.9	24.1		164.7				
	2SDev	0.7	0.1			0.1	0.0	0.6	0.6	0.1	0.0		5.8				
	Uncertainty	0.5	0.1			0.0	0.0	1.4	1.3	0.4	0.2		3.5				

Sheet steel, 5 Hz			TKS-DX56-L050-B12-5-Probe 2														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	52	158.87	163.87			303.86	2664.9	43.06	43.2	24.45	24.64		163	0.2	0.3		
2	52	159.39	164.28			303.86	2664.8522		44.14	24.34	24.63		162.69	0.2	0.3		
3	52	156.92	163.07			303.86	2664.8522		44.14	24.39	24.63		200	0.17	0.27		
4	52	158.8	163.8			303.9	2664.8525	43.4	43.5	24.5	24.6		166	0.2	0.3		
5	52	158.608	163.688			303.9	2664.9	43.064	43.197	24.5	24.6		174.067	0.191	0.294		
6	52	158.0251	163.4442			303.7284	2663.7	43.0665	43.1897	23.8621	24.0232		188.5495	0.17728	0.28016		
7	52	159.4	164.3			303.9	2665	44.1	44.1	24.4	24.6		145.2	0.195	0.3		
8	52	159.179	164.196	303.762		303.76	2664		0.422		22.25		148.621	0.196	0.3	22.25	
9	52	158.9	163.9			303.9	2665	43.36	44.144	24.438	24.627		161.25	0.188	0.292		
10	52	158.8	163.82			303.86	2664.85	43.35	43.48	24.44	24.63		165.1	0.2	0.3		
11	52	159.4	163.8			303.6	2662.94	44.15	44.14	23.89	24.09		165.28	0.2	0.29		
12	52	158.8	163.8			303.9	2665	43.4	43.5	24.5	24.6		167	0.186	0.289		
13	52																
14	52	159.12	164.04			303.86	2664.85			24.41	24.65		154.36				
	Agreed	158.5-158.9	163.6-163.9			303.9	2665	43.0-43.4	44.14	24.5	24.6		161.3-174.1	0.2	0.3		
	Mean	158.8	163.8			303.9	2664.7	43.2	44.1	24.4	24.6		164.3				
	2SDev	0.2	0.1			0.0	0.8	0.3	0.0	0.1	0.4		10.5				
	Uncertainty	0.1	0.1			0.0	0.0	0.8	0.1	0.4	1.5		6.4				

Sheet steel, 50 Hz			TKS-ZStE-180-L050-B12-5-Probe 1			**Comment**											
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	53	246.82	230.1	270.06	231.94	318.86	3781.6	40.37	40.39	18.93	19.09	1.74	204	0.22	0.31	0.16	1.89
2	53			270.06	228.66	318.86	3781.6796		40.82	18.86	19.08	1.93	198.653				
3	53			270.06	228.66	318.86	3781.6796		40.82	18.86	19.08	1.93	200				
4	53			270.1	228.7	318.9	3781.6375	40.8	40.8	18.9	19.1	1.8	204			0.2	0.3
5	53			270.064	233.633	318.9	3781.6	38.164	38.261	18.9	19.1	1.781	206.201			0.155	1.497
6	53			270.064	231.937	318.713	3779.9	37.9818	38.0947	18.6555	18.8118	1.65386	203.9792			0.15	1.8888
7	53	247.4	230.2	270.1	228.7	318.9	3782	40.8	40.8	18.9	19.1	1.801	203.8	0.214	0.309	0.15	0.277
8	53	245.53	230.016	265.767		318.718	3780		38.1		16.65		203.73	0.218	0.31	0.15	
9	53			270.6	228.2	318.9	3782	40.86	40.821	18.925	19.083	1.842	200.75			0.15	0.276
10	53	245.02	230.34	270.06	228.66	318.86	3781.64	38.07	38.17	18.93	19.08	1.739	204.2	0.22	0.31	0.15	0.277
11	53	246.9	230	270.06	231.9	318.6	3779.01	40.71	40.71	18.65	18.8	2.97	208.94	0.22	0.31	0.15	1.89
12	53			270.1	231.9	318.9	3782	40.8	40.8	18.9	19.1		204			0.15	1.889
13	53			270	232	319	3782	40.5	40.5	19	19	1.76	204			0.15	1.91
14	53			270.06	228.66	318.86	3781.64			18.93	19.09		204.04				
	Agreed			270.1	231.9	318.9	3782	40.3-40.8	40.82	18.9	19.1	1.74-1.8	198.7-208.9				
	Mean			270.1	231.9	318.9	3781.8	40.7	40.7	18.9	19.1		203.6				
	2SDev			0.1	0.1	0.1	0.4	0.4	0.3	0.2	0.1		5.0				
	Uncertainty			0.0	0.0	0.0	0.0	0.9	0.8	0.9	0.3		2.5				

Table B2 (contd): Summary of analysis returns (contd)

Sheet steel, 5 Hz			TKS-ZStE-180-L050-B12-5-Probe 1														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	55	246.97	229.93	270.05	232.02	318.79	3780.9	37.68	37.8	19.09	19.25	1.74	204	0.22	0.31	0.15	1.9
2	55			270.05	228.85	318.79	3780.8494		40.74	19.02	19.24	1.68	201.633				
3	55			270.05	228.85	318.79	3780.8494		40.74	19.02	19.24	1.68	200				
4	55			270	228.8	318.8	3780.8816	40.7	40.7	19.1	19.3	1.8	203			0.2	0.3
5	55			270.046	233.779	318.8	3780.9	37.958	38.071	19.1	19.2	1.783	205.399			0.153	1.456
6	55			270.046	232.017	318.7166	3780	37.678	37.7986	18.5419	18.6983	1.63965	203.8014			0.14784	1.89072
7	55	247.4	231.2	270	228.8	318.8	3781	40.7	40.7	19.1	19.2	1.743	203.8	0.214	0.336	0.148	0.282
8	55	246.543	230.016	270.151		318.718	3780		36.3		16.9		206.633	0.218	0.31	0.15	
9	55			270.6	229.3	318.8	3781	40.78	40.738	19.087	19.244	1.844	203.66			0.15	0.282
10	55	245.88	230.13	270.05	228.85	318.79	3780.88	37.95	38.07	19.09	19.24	1.743	205	0.22	0.31	0.15	0.282
11	55	247	229.8	270.05	232.1	318.6	3778.47	40.74	40.74	18.56	18.71	1.72	210.51	0.22	0.31	0.15	1.87
12	55			270	232	318.8	3781	40.4	40.5	19.1	19.2		204			0.148	1.891
13	55																
14	55			270.05	228.85	318.79	3780.88	37.96	38.07	19.09	19.25		203.27				
	Agreed			270.1	228.85	318.8	3781		40.74	19.1	19.25	1.74	201.6-210.5				
	Mean			270.0	232.0	318.8	3780.8	39.3	39.3	19.1	19.0		204.2				
	2SDev			0.1	0.1	0.1	0.7	3.0	3.2	0.1	1.3		5.0				
	Uncertainty			0.0	0.0	0.0	0.0	7.6	8.3	0.3	6.9		2.4				

Synthetic Digital Curve, 50 Hz			NPL Zero Noise														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	57	432.42	434.27			738.48	58000	49.97	50.24	39.64	40		207	0.31	0.41		
2	57	432.43	434.39			738.48	58000.219		50.24	39.3	40		207.5	0.31	0.42		
3	57	432.71	434.39			738.48	58000.219		50.24	39.27	40		200	0.32	0.42		
4	57	432.4	434.3			738.5	58000	50	50.2	39.6	40		208	0.3	0.4		
5	57	432.418	434.273			738.5	58000	49.937	50.211	39.6	40		207.5	0.308	0.409		
6	57	432.4175	434.2726			738.4789	58000.1	49.9681	50.2413	39.6308	39.9867		207.5	0.30839	0.40929		
7	57	432.4	434.4			738.5	58000	50	50.2	39.6	40		207.5	0.309	0.416		
8	57	432.58	434.49	738.158		738.158	57975		50.16		37.44		207.461	0.31	0.412	37.44	
9	57	432.4	434.3			738.5	58000	50.02	50.241	39.638	39.996		206.69	0.308	0.41		
10	57	432.42	434.27			738.48	58000	49.97	50.24	39.64	40		207.5	0.31	0.41		
11	57																
12	57	432.4	434.3			738.5	58000	50	50.2	39.6	40		207.5	0.308	0.409		
13	57	432	434			738	58000	49.9	50.2	39.6	39.9		207.5	0.31	0.41		
14	57	432.42	434.27			738.48	58000.00			39.64	40.00		207.50				
	Agreed	432.4	434.3			738.5	58000	50	50.2	39.6	40		207.5-208.0	0.31	0.41		
	Mean	432.4	434.3			738.4	58000.0	50.0	50.2	39.6	40.0		207.4				
	2SDev	0.2	0.2			0.3	0.2	0.1	0.0	0.2	0.1		0.6				
	Uncertainty	0.1	0.0			0.0	0.0	0.1	0.1	0.5	0.1		0.3				

Synthetic Digital Curve, 5 Hz			NPL Zero Noise														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	58	440.16	442.01			738.48	57999.9	49.83	50.1	39.56	39.92		208	0.31	0.41		
2	58	441.78	444.56			738.48	58000.219		50.1	39.23	39.92		207.5	0.4	0.55		
3	58	441.78	444.56			738.48	58000.219		50.1	39.2	39.92		200	0.4	0.55		
4	58	440.2	442			738.5	57999.948	49.8	50.1	39.6	39.9		208	0.3	0.4		
5	58	440.156	442.012			738.5	58000	49.522	49.801	39.6	39.9		207.5	0.312	0.413		
6	58	440.1561	442.012			738.5572	58006.3	49.8296	50.1045	39.3725	39.7284		207.5001	0.31212	0.41302		
7	58	441.8	444.6			738.5	58000	49.8	50.1	39.6	39.9		207.5	0.401	0.553		
8	58	440.22	442.13	738.158		738.15	57975		49.92		37.36		207.443	0.314	0.416	37.36	
9	58					738.5	58000	49.94	50.097	39.559	39.913		208.73	0.312	0.412		
10	58	440.16	442.01			738.48	57999.9	49.83	50.1	39.56	39.92		207.5	0.31	0.41		
11	58																
12	58	440.2	442			738.5	58000	49.8	50.1	39.6	39.9		207.5	0.312	0.413		
13	58																
14	58	440.16	442.01			738.48	57999.95			39.56	39.92		207.50				
	Agreed	440.1-440.2	442.0			738.5	58000	49.8	50.1	39.6	39.9		207.4-208.7	0.31	0.41		
	Mean	440.2	442.0			738.5	58000.6	49.8	50.1	39.5	39.9		207.7				
	2SDev	0.1	0.0			0.0	3.8	0.2	0.2	0.3	0.0		0.8				
	Uncertainty	0.0	0.0			0.0	0.0	0.5	0.4	0.8	0.1		0.4				

Table B2 (contd): Summary of analysis returns (contd)

Synthetic Digital Curve, 50 Hz			NPL 0.5% Load Noise														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	61	433.62	443.21	437.97	424.69	748.08	58754.5	49.96	50.24	39.21	39.57	0.21	207	0.31	0.41	0.24	0.34
2	61	428.12	444.11			748.08	58754.203		50.24	38.85	39.57		201.604	0.32	0.42		
3	61	428.12	433.96			748.08	58754.203		50.24	38.84	39.57		200	0.32	0.43		
4	61	433.8	442.3			748.1	58754.505	50	50.2	39.2	39.6		208	0.3	0.4		
5	61	434.033	438.888			748.1	58754.5	49.939	50.21	39.2	39.6		211.335	0.305	0.408		
6	61	433.8222	442.4663			738.4371	57996.9	49.9651	50.2413	39.0673	39.4229		207.6547	0.30932	0.41348		
7	61	433.8	444.1			748.1	58755	50	50.2	39.2	39.6		206.7	0.309	0.416		
8	61	433.53	441.17	482.238		744.843	58500		49.2		36.32		211.479	0.308	0.412	2.88	
9	61	433.9	441.3			748.1	58755	50.04	50.241	39.213	39.571		208.84	0.308	0.414		
10	61	433.85	442.09			748.08	58754.5	49.95	50.23	39.21	39.57		207.9	0.31	0.41		
11	61																
12	61	432.4	435.5			739.8	58100	49.8	50.1	39.3	39.7		206.7	0.309	0.41		
13	61	434	442			746	58630	50	50	39	39.5		208	0.31	0.41		
14	61	433.80	442.55			748.08	58754.51						207.12				
	Agreed	431.8-434.1	438.1-441.6			748.1	58754	50.0	50.2	39.2	39.6		201.6-211.5	0.31	0.41		
	Mean	433.7	441.5			748.1	58754.5	50.0	50.1	39.1	39.3		207.7				
	2SDev	0.9	0.9			0.0	0.6	0.1	0.6	0.3	1.9		5.0				
	Uncertainty	0.2	0.2			0.0	0.0	0.3	1.2	0.8	4.8		2.4				

Synthetic Digital Curve, 5 Hz			NPL 0.5% Load Noise														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	62	438.72	438.72	437.09	432.8	745.08	58518.5	49.82	50.11	36.52	36.88		203	0.32	0.42	0.23	0.24
2	62	444.56	443.9			745.08	58518.583		50.1	36.11	36.88		180.198	0.4	0.55		
3	62	444.56	443.9			745.08	58518.583		50.1	36.18	36.88		200	0.4	0.55		
4	62	438.6	444.5			745.1	58518.515	49.8	50.1	36.5	36.9		206	0.3	0.4		
5	62	438.413	444.509			745.1	58518.5	49.526	49.798	36.5	36.9		211.206	0.308	0.41		
6	62	438.5994	444.4968			740.1131	58128.5	49.8238	50.1045	37.6638	38.0239		205.5293	0.31268	0.41555		
7	62	444.6	443.9			745.1	58519	49.8	50.1	36.5	36.9		204.6	0.401	0.553		
8	62	439.26	444.99	587.28		744.84	58500		49.2		36.88		206.605	0.314	0.418	9.36	
9	62					745.1	58519	49.94	50.097	36.512	36.873		206.87	0.312	0.414		
10	62	438.53	444.5			745.08	58518.5	49.68	49.95	36.52	36.88		207.8	0.31	0.41		
11	62																
12	62	437.5	441.5			741	58200	49.5	49.8	37.9	38.2		206.3	0.312	0.414		
13	62																
14	62	438.58	444.50			745.08	58518.52						205.53				
	Agreed	438.3-438.9	444.1			745.1	58519	49.8	50.1	36.5	36.9		203.0-211.2	0.31	0.42		
	Mean	438.6	444.5			745.1	58518.6	49.7	50.0	36.7	37.1		206.3				
	2SDev	0.2	0.0			0.0	0.4	0.3	0.6	1.2	1.0		4.3				
	Uncertainty	0.0	0.0			0.0	0.0	0.6	1.1	3.3	2.7		2.1				

Synthetic Digital Curve, 50 Hz			NPL 1% Load Noise														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	63	430.35	430.35	428.9	403.3	759.26	59632.4	49.96	50.24	37.29	37.66		206	0.31	0.42	0.21	0.21
2	63	427.48	441.89			759.26	59632.28		50.24	36.89	37.66		186.298	0.32	0.43		
3	63	430.04	448.42			759.26	59632.28		50.24	36.94	37.66		200	0.31	0.42		
4	63	430.9	448.2			759.3	59632.385	50	50.2	37.3	37.7		207	0.3	0.4		
5	63	432.338	448.268			759.3	59632.4	49.941	50.21	37.3	37.7		211.631	0.304	0.412		
6	63	429.8727	447.1028			740.3684	58148.5	49.9565	50.2413	37.8715	38.2363		202.9707	0.31029	0.41878		
7	63	430	448.4			759.3	59632	50	50.2	37.3	37.7		205.3	0.309	0.416		
8	63	429.71	447.86	446.906		754.39	59250		50.08		38		205.901	0.31	0.418	0.56	
9	63	430.9	444.7			759.3	59632	50.04	50.241	37.288	37.655		206.87	0.308	0.416		
10	63	430.74	448.12			759.26	59632.4	49.96	50.23	37.29	37.66		207.2	0.31	0.42		
11	63																
12	63	432.3	435.2			740.5	58160	49.8	50.1	37.4	37.7		207.3	0.309	0.41		
13	63																
14	63	430.68	448.05			83.78	6579.94						206.36				
	Agreed	429.6-432.7	446.5-448.2			759.3	59632	50.0	50.2	37.3	37.7		203.0-211.6	0.31	0.42		
	Mean	430.7	447.9			759.3	59632.3	50.0	50.2	37.3	37.8		206.0				
	2SDev	1.8	0.9			0.0	0.3	0.1	0.1	0.5	0.4		5.7				
	Uncertainty	0.4	0.2			0.0	0.0	0.3	0.2	1.4	1.0		2.8				

Table B2 (contd): Summary of analysis returns (contd)

Synthetic Digital Curve, 5 Hz			NPL 1% Load Noise														
Lab ID	Data set ID	Rp0.1	Rp0.2	ReH	ReL	Rm	Fm	A	At	Ag	Agt	Ae	E	A0.1	A0.2	AeH	AeL
1	64	439.02	439.02	447.72	445.13	754.95	59293.6	49.66	49.95	39.25	39.62	0.46	203	0.32	0.42	0.25	0.86
2	64	441.08	447.69			754.95	59293.773		50.1	38.91	39.62		208.102	0.4	0.55		
3	64	441.08	447.69			754.95	59293.773		50.1	38.88	39.62		200	0.4	0.55		
4	64	439	441.8			754.9	59293.578	49.8	50.1	39.2	39.6		204	0.3	0.4		
5	64	438.652	441.116			754.9	59293.6	49.533	49.792	39.3	39.6		228.983	0.292	0.393		
6	64	438.9144	441.5952			739.3952	58072.1	49.8401	50.1045	38.0993	38.4517		209.8182	0.31101	0.41229		
7	64	437.4	441.1			754.9	59294	49.8	50.1	39.3	39.6		206.9	0.249	0.401		
8	64	439.26	441.17	455.5		755.34	59325		49.76		39.6		217.896	0.308	0.41	0.72	
9	64					754.9	59294	49.94	50.097	39.241	39.609		205.57	0.312	0.412		
10	64	439	441.76			754.95	59293.6	49.66	49.95	39.24	39.62		202.4	0.32	0.42		
11	64																
12	64	439.9	444			744.6	58480	49.5	49.8	39.3	39.6		209.2	0.312	0.414		
13	64																
14	64	439.08	441.91			754.95	59293.58			0.48	0.71		197.15				
	Agreed	438.8-439.0	441.4-441.8			755.0	59294	49.7	50.0	39.3	39.6		202.4-209.8	0.3	0.4		
	Mean	439.2	441.5			754.9	59293.7	49.7	50.0	39.2	39.6		204.6				
	2SDev	0.8	0.7			0.1	0.4	0.3	0.3	0.3	0.0		8.2				
	Uncertainty	0.2	0.2			0.0	0.0	0.6	0.6	0.8	0.1		4.0				