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International round robin test for tensile testing HTS wires at cryogenic temperatures

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Abstract

Within the framework for establishing standards of test methods for superconducting technical wires, various standards have been issued by the International Electrotechnical Commission (IEC) (standard documents IEC 61788-1 to -20). Following the successful round robin test (RRT) for tensile testing REBCO wires at room temperature (Osamura K *et al* 2014 *Supercond. Sci. Technol.* **27** 085009), this effort is extended to tensile test HTS wires at cryogenic temperatures and is coordinated by the CryoMaK lab at Karlsruhe Institute of Technology. Five different commercially available REBCO wires from five different manufacturers and one BiSCCO wire from another supplier were provided by the Versailles Project on Advanced Materials and Standards (<http://vamas.org>) for testing. Samples were distributed between eight participating labs from five different countries for testing according to the specified guidelines. After the test results were delivered by all participants, the data were evaluated with statistical tools to investigate the main source of scatter and its magnitude in the test results. The final goal of the RRT is issuing an ISO/IEC standard for a cryogenic temperature tensile test for REBCO wires. In this report the results of the RRT for tensile testing REBCO wires at cryogenic temperatures are presented and discussed.

Keywords: high temperature superconducting wires, REBCO, BSCCO, modulus of elasticity, 0.2% proof strength, standardization, international RRT

(Some figures may appear in colour only in the online journal)

1. Introduction

In the growing field of superconducting applications lot of effort has been put into standardization work for commercially available superconducting wires. Recently, international round robin tests (RRTs) were performed for the measurements of critical currents on Nb₃Sn [1] and REBCO [2] superconductors, the retained critical current measurement

after double bending in Bi2223 wires [3], and so on. Especially for magnet applications, where the superconducting wires are subject to extremely large Lorentz forces, the mechanical tests on superconducting wires are very important.

A number of tensile test investigations have been already performed for HTS wires and they can be found in the literature. These studies are mostly focused on the investigation

of effect of the tensile stress on critical current. In [4] it was shown that irreversible strain (stress) is intrinsically determined by permanent damages in the conductor, and strongly affected by the mechanical properties of the substrate and stabilizer materials. Sugano *et al* [5] found that quenching in REBCO wires under tension is attributed to the discontinuous yielding of the Hastelloy C-276 substrate. The effect of the stabilizer on performance of the wire under tensile stress was investigated in [6, 7] for different copper stabilizing layer thicknesses, and for additional brass stabilizing layer.

Despite all these efforts, international standards to properly measure and report the tensile properties of an HTS wire at cryogenic temperatures an international standard are needed.

A number of RRTs for tensile testing at room temperature have been already successfully completed for Nb₃Sn [8], BiSCCO [9], and REBCO [10] wires. Following this experience, an international RRT for tensile testing HTS wires at cryogenic temperatures was promoted by the Versailles Project on Advanced Materials and Standards and supported by the International Electrotechnical Commission.

In the present paper the results of this international, multi-laboratory effort are shown and discussed.

2. Round robin test (RRT)

2.1. Samples

Five commercially available REBCO wires and one BiSCCO wire were purchased from six manufactures. Specifications of the conductors as reported by the manufacturers are shown in table 1. Each conductor was cut in 1 m long pieces. All six conductors were wound on the same bobbin, and eight identical bobbins were distributed between eight participating labs from six different countries.

2.2. Testing procedure and evaluation of results

The testing procedure was described in the guideline sent to participants. The guideline for a RRT at low temperature is based on corresponding guideline for a RRT at room temperature [11] adopted for a cryogenic environment as described below.

Each conductor was cut by each participant in appropriate pieces according to the requirements of their testing apparatus, taking into account the following empirical formula for the specimen length:

$$L = 2L_g + L_{GL} + 2L_x, \quad (1)$$

where L_g is the grip length, and L_{GL} is the gauge length of the extensometer. L_x is the free gap distance between grip and extensometer and is given by the condition [10]:

$$L_x = 0.7L_{GL}. \quad (2)$$

The tapes were installed in a tensile machine in such a way that pre-bending or pre-loading of the sample was avoided. The extensometers used have very sharp edges so that they could be set on the test specimen avoiding deformation of the specimen.

The tensile test was performed at liquid nitrogen temperature. For that, the cryostat was filled with liquid nitrogen, so that the sample with extensometers was immersed in the liquid nitrogen bath. The participants were asked to avoid pre-loading of the specimen due to thermal contraction during cool down, for example, activating force-free mode in the tensile machine or using an unloading fixture.

Special requirements had to be fulfilled for the extensometers used for low temperature test. Their active elements had to be operable at cryogenic liquid that is required for effective cooling. The bridge voltage of the strain gauge system had to be lowered to ensure the lowest possible power consumption. That prevented the influence of heating of the strain gauges on the strain signal due to bubbles on the gauge grid. As the extensometer calibration factor might vary with temperature, the extensometer had to be calibrated at the test temperature.

The main parameters of the measurement setup and test conditions in every lab are summarized in table 2.

The test was performed as follows: tensile stress was applied to the specimen monitoring stress and strain. When the total strain had reached a value of approximately 0.1%–0.15%, the tensile force was reduced by approximately 30%–40%. Then, the load was increased again to the previous level and the test was continued until fracture (or up to the load or extension limits of each setup).

From the measured stress–strain dependence (see figure 1), the modulus of elasticity was calculated from the straight portion of the initial loading curve (E_0) and of the unloading one (E_U) using the following formula:

$$E = \Delta F / (S_o \Delta A), \quad (3)$$

where E is modulus of elasticity in GPa, ΔF is increment of the corresponding force in kN, S_o is the original sample cross-sectional area in mm², and ΔA is the increment of the strain.

After each test the results are qualified using the following criterion:

$$1 - \delta < E_0 / E_U < 1 + \delta (\delta = 0.3). \quad (4)$$

0.2% proof strength ($R_{p0.2-0}$ and $R_{p0.2-U}$) are determined from the initial loading part and the unloading/reloading part of the stress–strain curve, respectively. Each 0.2% proof strength was calculated using equation (5):

$$R_{p0.2-i} = F_i / S_o, \quad (5)$$

where $R_{p0.2-i}$ is the 0.2% proof strength in MPa at each point, F_i is the force at each point in kN.

Table 1. HTS wires for the RRT.

	C1	C2	C3	C4	C5	C6
Width, mm	12	4	4	4	4	4.5
Thickness, mm	0.14–0.16	0.15	0.128 ^a	0.094	0.1	0.3
Substrate material	Hastelloy C-276	non-magnetic stainless steel	Hastelloy C-276	Hastelloy C-276	Hastelloy C-276	
Substrate thickness, μm	100	100	75	50	60	
Stabilizer material	copper	copper	copper	copper	copper	
Total stabilizer thickness, μm	40 (2 $\times$ 20)	40 (22 $\times$ 20)	40 (22 $\times$ 20)	40 (22 $\times$ 20)	40 (22 $\times$ 20)	
Matrix material						Ag and Ag alloy
Reinforcing material						nickel alloy
Matrix thickness, μm						250
Total reinforce thickness, μm						60 (2 $\times$ 30)

^a The value as estimated from measurements.

Table 2. Tensile test setups and test parameters.

	A	B	C	D	F	E	G	H
Test temperature, K	77.1–77.3	77.3–77.4	77.3	77.5	77.46–77.36	77.3		77.3–77.4
Initial strain rate	$2.5 \times 10^{-5} \text{ s}^{-1}$	$6.9 \times 10^{-5} \text{ s}^{-1}$	1 mm min^{-1}	$3.5 \times 10^{-5} \text{ s}^{-1}$	0.06 mm min^{-1}	$1.6 \times 10^{-4} \text{ s}^{-1}$	0.5 mm min^{-1}	0.18 mm min^{-1}
Distance between grips, mm	120	120	60	100	72	100		60
Manufacturer and model of tensile machine	Shimadzu, AG-IC	MTS 250 kN Machine with 10 kN Load Cell	Shimadzu AG-IS 5 kN	10 kN anti-backlash machine screw actuator: Duff-Norton M5500-124	Chinese tensile machine with max load of 200 kg.	Shimadzu AG-50kNIS	MTS servo hydraulic	PVLS with maximum force, travel and resolution of 20 kN, 200 and $0.05 \mu\text{m}$
Model of extensometer	Nyilas-type double ext.	Shepic 50 mm GL ext.	Nyilas-type double ext.	Nyilas-type double ext.	Cryoall, Model: CLN-UL	Nyilas-type double ext.	Nyilas-type double ext.	Nyilas-type double ext.
Gripping method	Screw tighten	Bolt-together clamp	Screws with the insertion of sand papers	Stainless steel compression style sample grips	Copper plates inserted between the specimen and grips	Brass plate holder	Clamping / knurled surface	Brass grip holders screws with the insertion of sand papers
Cooling rate, K min^{-1}	80	50	20	4.8	20	50	20	15
Unloading method	auto zero-force mode	load control mode	load control mode	load control mode	load control mode	load control mode	unloading fixture	force-free mode

Figure 1. Stress–strain curve for conductor C2.

3. Round robin test results

3.1. Experimental results

Figures 2 and 3 show data sets for the modulus of elasticity E_0 and the proof strength $R_{p0.2-0}$ for the conductor C2 obtained from all participants. Results for the other conductors and another pair of data E_U and $R_{p0.2-U}$ look similar to the data shown on these two figures. Comparing figure 2 with respective figure 3 from [10], representing E_0 results for room temperature RRT, we can conclude that the scattering in the results is similar in both cases.

Every sample was tested five times ($J = 5$) by every participant, $K = 8$ is the number of participants, so the total number of measurements for each conductor is $N = K * J = 40$. Since several data could not be obtained for conductor C1 (due to limitation of the load cell measurement range), the number of tests is 35 and 30 for E_0 and $R_{p0.2-0}$, respectively, instead of 40 in both cases.

Type-A and type-B uncertainty analyses are described in detail in [12]. Further, we perform both analyses for data obtained in RRT.

3.2. Type-A uncertainty analysis

The average of N measurands is given by the equation [10]:

$$\langle q \rangle = \left(\frac{1}{N} \right) \sum_{j=1}^J \sum_{k=1}^K q_{jk}, \quad (6)$$

where q_{jk} is E_{0jk} , E_{Ujk} , $R_{p0.2-0jk}$, and $R_{p0.2-Ujk}$ are single measurements, and $\langle E_0 \rangle$, $\langle E_U \rangle$, $\langle R_{p0.2-0} \rangle$, and $\langle R_{p0.2-U} \rangle$ their total averages, respectively.

Standard uncertainty is given by the equation [10]:

$$s(\bar{q}) = \sqrt{\frac{1}{(N-1)N} \sum_{i=1}^N (q_i - \langle q \rangle)^2} \quad (7)$$

and relative standard uncertainty (RSU/%) is defined as

$$\text{RSU} = 100 \frac{s(\bar{q})}{\langle q \rangle}. \quad (8)$$

Figure 2. E_0 data at 77 K for conductor C2 from all participants.

Figure 3. $R_{p0.2-0}$ data at 77 K for conductor C2 from all participants.

Tables 3 and 4 summarize total average for modulus of elasticity E_0 and 0.2% proof strength $R_{p0.2-0}$ and their relative standard uncertainties, respectively. RSU values from table 3 can be compared with respective RSU values for modulus of elasticity from room temperature RRT (see table 3 in [10]). The conclusion is that also here results are similar to each other. Similar results were obtained for of E_U and $R_{p0.2-U}$.

In order to indicate the major scatter source, analyses of variance (ANOVA) were performed for all RRT results. In these analyses the inter-laboratory estimate $s_a^2(\nu_a)$ and the intra-laboratory estimate $s_b^2(\nu_b)$ (see formulas in [10]), where $\nu_a = J - 1$ and $\nu_b = J(K - 1)$, were calculated. Further, an experimental F -value was found as

$$F = \frac{s_a^2(\nu_a)}{s_b^2(\nu_b)}. \quad (9)$$

This was compared with theoretical critical $F_{0.95}(f_a, f_b)$ value, which could be found in the statistical tables for this

Table 3. Average modulus of elasticity E_0 and y for all conductors.

E_0 /GPa	C1	C2	C3	C4	C5	C6
Number of tests	35	40	40	40	40	40
Mean value	166.79	166.67	159.68	143.87	153.88	108.13
RSU/%	1.51	1.88	1.65	1.67	2.28	1.61

Table 4. Average 0.2% proof strength $R_{p0.2-0}$ and relative standard uncertainty for all conductors.

$R_{p0.2-0}$ /MPa	C1	C2	C3	C4	C5	C6
Number of tests	30	40	40	40	40	40
Mean value	942.71	605.98	989.05	810.03	936.15	504.34
RSU/%	0.82	1.26	0.83	1.40	1.17	1.01

Table 5. ANOVA results for E_0 for all conductors.

E_0 /GPa	C1	C2	C3	C4	C5	C6
Number of tests	35	40	40	40	40	40
F -value	48.48	39.29	48.59	36.78	23.83	33.43
$F_{0.95}(f_a, f_b)$	2.45	2.31	2.31	2.31	2.31	2.31

RRT configuration. Based on this comparison, a conclusion about the major scatter source on the data can be obtained.

Results of ANOVA for E_0 and $R_{p0.2-0}$ are summarized in tables 5 and 6, respectively. One can conclude that inter-laboratory scattering is significantly larger than intra-laboratory scattering, since the experimental F -values are everywhere larger than the theoretical values.

4. Discussion

4.1. Type-B uncertainty analysis

Type-B uncertainty analysis was performed following the procedure described in [13] for the uncertainty evaluation in mechanical tests on metallic materials. For the modulus of elasticity, expression (3) can be rewritten as follows:

$$E = \frac{\Delta F}{S_0 \Delta A} = m_E \frac{L_0}{S_0}, \quad (10)$$

where L_0 is the original gauge length, m_E is the slope of the linear part of the force–displacement curve. Thus, three uncertainty sources should be considered: (i) L_0 , (ii) S_0 , and

(iii) m_E . Combined uncertainty of E can be written as

$$u_E = \sqrt{\left(\frac{L_0}{S_0}\right)^2 S_{m_E}^2 + \left(\frac{m_E}{S_0}\right)^2 u_{L_0}^2 + \left(\frac{L_0 m_E}{S_0^2}\right)^2 u_{S_0}^2}, \quad (11)$$

where S_{m_E} , u_{L_0} , and u_{S_0} are corresponding uncertainties for m_E , L_0 , and S_0 . For the cross-sectional area evaluation several measurements of the tape dimensions along the length and across the width of HTS wire were requested, in order to take into account possible inhomogeneity in wire thickness that is not unusual for most HTS wires.

Considering the cross-sectional area having rectangular shape, the combined uncertainty for S_0 was calculated using the following formula:

$$u_{S_0} = \sqrt{b_0^2 u_{a_0}^2 + a_0^2 u_{b_0}^2}, \quad (12)$$

where a_0 and b_0 are thickness and width of the wire, and u_{a_0} and u_{b_0} are their corresponding uncertainties. The total uncertainty budget for modulus of elasticity for the sample C2 no. 5 tested by laboratory G (further C2-05 G) is presented in table 7.

Comparing contributions from different uncertainty sources for the modulus of elasticity, we can conclude that the major contribution (about 82% of total uncertainty value) is associated with the cross-sectional area evaluation.

For the proof stress evaluation, permanent strain should be defined from force–displacement data (e_{IP} , F_{IP}) as follows:

$$\varepsilon_p = \frac{e_{IP}}{L_0} - \frac{F_{IP}}{L_0 m_E}. \quad (13)$$

Force F_{ε_p} and displacement e_{ε_p} at $\varepsilon_p = 0.002$ is the associated data pair for the proof stress (see figure 4).

Uncertainty sources for the permanent strain are (i) extensometer displacement e_p , (ii) original gauge length L_0 , associated force at 0.002 permanent strain F_{ε_p} , and (iii) slope m_E . Thus, the combined uncertainty of ε_p was calculated as follows:

$$u_{\varepsilon_p} = \sqrt{\left(\frac{1}{L_0}\right)^2 u_{e_p}^2 + \left(-\frac{e_{\varepsilon_p}}{L_0^2} + \frac{F_{\varepsilon_p}}{m_E L_0^2}\right)^2 u_{L_0}^2 + \left(-\frac{1}{m_E L_0}\right)^2 u_{F_{\varepsilon_p}}^2 + \left(\frac{F_{\varepsilon_p}}{m_E^2 L_0}\right)^2 u_{m_E}^2}, \quad (14)$$

Table 6. ANOVA results for $R_{p0.2-0}$ for all conductors.

$R_{p0.2-0}/\text{MPa}$	C1	C2	C3	C4	C5	C6
Number of tests	30	40	40	40	40	40
F -value	13.04	141.86	211.37	63.11	74.23	79.44
$F_{0.95}(f_a, f_b)$	2.53	2.31	2.31	2.31	2.31	2.31

where u_{F_p} , u_{L_0} , and u_{m_E} are the corresponding uncertainties of sources of uncertainty.

Further, the proof strength is calculated as:

$$R_{p0.2} = \frac{F_{\varepsilon_p}}{S_0}. \quad (15)$$

Therefore uncertainties sources are the force at 0.002 permanent strain, and original cross-sectional area. Uncertainty in F_{ε_p} at $\varepsilon_p = 0.002$ are coming (1) from determination of ε_p , u_{F_p} , and (2) from force reading depending on class of force transducer u_F :

$$u_{FC_{\varepsilon_p}} = \sqrt{u_{F_{\varepsilon_p}}^2 + u_F^2}, \quad (16)$$

where u_{F_p} can be determined from a parabolic fitting function $F_{\varepsilon_p} = \alpha_2 \varepsilon_p^2 + \alpha_1 \varepsilon_p + \alpha_0$ as shown in figure 2 for the particular case of the force–permanent strain curve for the sample C2-05 G with the expression:

$$u_{F_p} = \sqrt{(2\alpha_2 \varepsilon_p + \alpha_1)^2 u_{\varepsilon_p}^2}. \quad (17)$$

Summarizing, the combined uncertainty of $R_{p0.2}$ is calculated as

$$u_{R_{p0.2}} = \sqrt{\left(\frac{1}{L_0}\right)^2 u_{FC_{\varepsilon_p}}^2 + \left(\frac{F_{\varepsilon_p}}{S_0^2}\right)^2 u_{S_0}^2}. \quad (18)$$

Uncertainty budget calculation for the sample C2-05 G is represented in table 8. Analysis of the contributions from different sources of uncertainties indicates that for both permanent strain and proof stress (and contrary to the modulus of elasticity) there is no source, which has a significant larger contribution than other uncertainty sources.

4.2. Comparison between type-A and -B uncertainties

Further, we can compare type-A and type-B uncertainties. For this comparison, the full set of data for conductor C2 should be considered. For modulus of elasticity RSU was found to be 1.88% (table 3). It is lower than 2.95% of expanded uncertainty reported in table 7 for the sample C2-05 G. For the proof strength, the type-A and type-B uncertainties are 1.26% and 3.5% (table 8), respectively. Type-A values are covered with type-B values. This means that the uncertainties for the measurements of E_0 and $R_{p0.2}$ are well explained by the sources, which were considered in the type-B analysis.

4.3. Correlation between measurement of the cross-sectional area, modulus of elasticity and proof strength

Considering that the major source of uncertainty for the modulus of elasticity in the type-B analysis was found to be

cross-sectional area evaluation, ANOVA was performed for statistical data for S_0 , which were available from seven participants. For the conductor C2 the experimental and theoretical F -values were 16.68 and 2.45, respectively. This indicates that also here the major scatter source was attributed to the variance among the data reported by seven labs.

As it was already mentioned above, the thickness of an HTS wire is often very inhomogeneous: a dog-boning or lens shape of cross-sectional area of the wire was often observed. This should be taken into account, and several measurements of the wire thickness should be performed in different positions across the width and along the length, and averaged value should be used for S_0 calculation. It is also important to use an appropriate micrometer that does not deform the soft copper surface of the HTS wire. All these factors might affect strongly the evaluation of cross-sectional area, and lead to sufficient scattering in the data.

In order to investigate a possible correlation between the modulus of elasticity and thickness of a wire, partial average of the modulus of elasticity normalized by the total average of the modulus of elasticity for each conductor was plotted versus average thickness measured by each participant (see figure 5). A linear regression was applied and Pearson's correlation coefficient R was calculated to investigate the strength of linear relationship between data.

It is seen from figure 5 that there is almost no correlation between modulus of elasticity and wire thickness for conductors C3 and C6. Here the data might be scattered due to other experimental factors. For other wires, the modulus of elasticity can be considered as inversely proportional to the wire thickness. This is predicted by formula (3), considering that S_0 is the product of thickness and width of the wire. Pearson's correlation coefficient is between -0.55 and -0.74 for samples C1, C2, C4, and C5, which deviates from the value -1 corresponding to a good correlation.

Summarizing, we can conclude that cross-sectional area evaluation is a significant uncertainty source for results of tensile test on HTS wires, but there are also further important experimental factors, which contribute remarkably in data scattering.

4.4. Qualification condition

As it was mentioned in section 2.2, the criteria given with formula (4) (where the parameter σ was set to 0.3) were used in order to qualify the results. This σ parameter can be set to lower values to make the qualification criteria stronger. For example, setting the criteria $\sigma = 0.1$, 28.7% of the results become unqualified. However, unqualified data are distributed non-homogeneously over the samples: with $\sigma = 0.1$, 55% of results for BiSCCO wire become unqualified, while

Table 7. Uncertainty budget calculation for modulus of elasticity for sample C2-05 tested in lab G.

Symbol	Value X_i	Sensitivity coefficient $\frac{\partial E}{\partial X_i}$	Uncertainty value u_{X_i}	Type	Probability distribution	Divisor	$\frac{\partial E}{\partial X_i} u_{X_i}$
L_0	12.98 mm	13.49	± 0.1 mm	B	rectangular	$\sqrt{3}$	± 0.78 GPa
S_0	0.558 mm ²	303.9	± 0.008 mm ²	B	triangular	1	± 2.43 GPa
m_E	7.53 kN mm ⁻¹	23.26	± 0.0095 kN mm ⁻¹	A	normal	1	± 0.22 GPa
E	combined uncertainty	± 2.56 GPa	$\pm 1.47\%$	A + B	normal		
	expanded uncertainty ($k = 2$)	± 5.12 GPa	$\pm 2.95\%$	A + B	normal		

Table 8. Uncertainty budget calculation for proof strength for sample C2-05 tested in lab G.

Symbol	Value X_i		Sensitivity coefficient $\frac{\partial \varepsilon_p}{\partial X_i} / \frac{\partial R_{p0.2}}{\partial X_i}$		Uncertainty value u_{X_i}		Type	Probability distribution	Divisor	$\frac{\partial \varepsilon_p}{\partial X_i} u_{X_i} / \frac{\partial R_{p0.2}}{\partial X_i} u_{X_i}$	
e_{ε_p} (associated)	0.026	mm	0.077	mm^{-1}	$\pm 1.5 \times 10^{-3}$	mm (class 0.5)	B	rectangular	$\sqrt{3}$	$\pm 6.67 \times 10^{-5}$	
L_0	12.98	mm	-4.57×10^{-4}	mm^{-1}	± 0.1	mm	B	rectangular	$\sqrt{3}$	$\pm 2.62 \times 10^{-5}$	
F_{ε_p} (associated)	0.373	kN	-0.01	kN^{-1}	± 0.006	kN	B	rectangular	$\sqrt{3}$	$\pm 3.46 \times 10^{-5}$	
m_E	7.53	kN mm^{-1}	5.40×10^{-4}	mm kN^{-1}	± 0.0095	kN mm^{-1}	A	normal	1	$\pm 5.13 \times 10^{-6}$	
ε_p	combined uncertainty		$\pm 7.97 \times 10^{-5}$		$\pm 3.99\%$		A + B	normal			
F_{ε_p} force at $\varepsilon_p = 0.002$	0.373	kN	1.79	mm^{-2}	± 0.00375	kN	A + B	normal	1	± 0.0067	GPa
S_0	0.558	mm^2	1.20	kN mm^{-4}	± 0.008	mm^2	B	triangular	1	± 0.0096	GPa
$R_{p0.2}$	combined uncertainty		± 11.69	MPa	$\pm 1.75\%$		A + B	normal			
	expanded uncertainty ($k = 2$)		± 23.38	MPa	$\pm 3.5\%$		A + B	normal

Figure 4. Force–permanent strain curve for the sample C2-05 G.

Figure 5. Partial average of modulus of elasticity normalized by the total average of modulus of elasticity for each conductor versus normalized average thickness measured by each participant. Linear regression lines and Pearson's correlation coefficients R are shown.

for REBCO wires the number of unqualified results become 14.7%. That is in good agreement with the results obtained with the room temperature RRT [10].

5. Conclusions

The international RRT for tensile testing HTS wires at liquid nitrogen temperature was performed for six commercially available HTS wires. The results were obtained from eight different laboratories for four measured quantities E_0 , $R_{p0.2-U}$, E_U , and $R_{p0.2-U}$. Statistical analysis was carried out to investigate scattering in the data. It was found that the major source of scatter can be attributed to the variance among the data reported by the participants. Comparison types A and B analysis showed that RSU values are covered by uncertainty

values, which were calculated considering uncertainty sources in the type-B analysis. For the modulus of elasticity in the type-B analysis the major contribution of scatter is arising from the evaluation of the cross-sectional area. Further analysis showed that there might be other uncertainty sources (i.e. alignment of the sample and extensometers might cause some shear strain that was not taken into account, factors related to cryogenic environment, for example presence of ice might add friction to the process of loading and unloading, results evaluation procedure, for example in determining the starting point for the loading process during an experiment), which contribute significantly in the scattering of data.

Further steps towards the international standard will include more detailed investigation of the sources of uncertainty. For example, to address the cross-sectional area evaluation, the same sample can be measured by all participants in order to check the methodology and measurement of the cross-sectional area. The extensometer and load cell calibration procedures can also be re-examined to provide more precise specification in the guideline.

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