IOP Conference Series: Materials Science and Engineering

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To cite this article: P Konopík *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **179** 012039

IOP Conf. Series: Materials Science and Engineering **179** (2017) 012039 doi:10.1088/1757-899X/179/1/012039

Correlation between standard Charpy and sub-size Charpy test results of selected steels in upper shelf region

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Abstract. Absorbed energy obtained from impact Charpy tests is one of the most important values in many applications, for example in residual lifetime assessment of components in service. Minimal absorbed energy is often the value crucial for extending components service life, e.g. turbines, boilers and steam lines. Using a portable electric discharge sampling equipment (EDSE), it is possible to sample experimental material non-destructively and subsequently produce mini-Charpy specimens. This paper presents a new approach in correlation from sub-size to standard Charpy test results.

1 Introduction

Degradation of the properties of metal materials can lead to loss of reliability and safety of machines and metal structures in power plants during their operation. However, a number of these machines or metal structures could be used for longer time than has been predicted by their designed lifetime.

A component's residual life can be evaluated by standard mechanical test techniques, such as the tensile test, the fatigue test, the Charpy or the fracture toughness test. However, for these tests there is usually insufficient material to sample non-invasively from the component. Therefore, non-destructive techniques are being developed as well as testing methods using mini-samples.

One of the widely used methods of mini-samples testing is the Small Punch Test (SPT) [1]. The SPT is usually based on conversion of the obtained results into conventional mechanical characteristics [1].

However, it requires known correlation parameters determined for the specific material and these correlation parameters must be verified for each new material. On the other hand, there exist small specimen testing techniques respecting the same loading mode as in the case of standard samples. Namely, it is the micro-tensile test [4]-7], the miniature fracture toughness test [8-9], the miniature fatigue test [10-[10] and the mini-Charpy test for DBTT determination [12[15].

Furthermore, these methods maintain minimal material requirements without requiring previously established correlations or at least they use a much more reliable type of correlation (without necessity to measure wide range material database).

Above mentioned miniaturized testing techniques have already been verified. This paper intends to extend these testing methods to correlation from mini-Charpy results to standard Charpy results in the upper shelf region.

2 Experimental material

Five structural steels used mostly in automotive or power industries were used as experimental materials.

The materials were delivered as semi-products in the form of a rod or a tube. Three of them were experimental steels (m06, m08, m11) and the others were 34CrNiMo6 (m15) and AK1TD steels. Chemical composition of each material is stated in table 1 and their mechanical properties in table 2.

Table 1. Chemical composition (wt. %).

Material	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	W
m06	0.305	0.275	0.750	0.008	0.002	1.025	0.200	0.150	0.100	-
m08	0.180	0.280	1.400	0.004	0.001	0.200	0.027	0.067	0.067	-
m11	0.170	0.330	1.450	0.008	0.002	0.250	0.053	0.133	0.133	-
m15	0.340	0.200	0.650	0.013	0.018	1.500	0.225	1.500	-	-
AK1TD	0.048	0.260	0.480	0.009	0.001	10.68	0.370	1.670	0.028	1.376

Table 2. Tensile test results.

Material	YS (MPa)	UTS (MPa)	Uniform Elongation (%)	Elongation 5D (%)	Area Reduction (%)
m6	969,1	1039,4	5,4	17,9	65,9
m8	1145,5	1252,1	2,5	14,3	70,2
m11	981,1	1022,1	4,7	17,5	70,9
m15	932,0	1034,2	5,4	15,6	55,8
AK1TD	837.1	941,9	6,3	18,1	58,4

3 Experiment

In order to describe the fracture behaviour of the material depending on the size factor in the upper shelf region, only materials showing full ductile damage at room temperature were chosen. In all cases, full size Charpy specimen as well as mini-Charpy specimens were tested. Moreover, in order to better understand the fracture behaviour, standard Charpy specimens with reduced thickness were tested in the case of three materials. Furthermore, most of the materials were tested in longitudinal and transversal direction.

Charpy-V specimens with a height of 10 mm and various widths (10 mm, 7.5 mm, 5 mm, 2.5 mm) and mini-Charpy specimens with a cross-section of 3x4 mm [16-17] are shown in figure 1.

Impact tests were performed using a 300 J pendulum with striking edge radius of 2 mm for standard specimens and a 15 J pendulum with striking edge radius of 2 mm for mini-Charpy specimens. For each testing condition, at least three repetitions were performed. After the test, absorbed energy KV was measured and instrumented record was captured. An example of instrumented records is depicted in figure 2. All records show full ductile damage which is consistent with fracture appearance of broken specimens. Absorbed energy was transformed to the notch toughness KCV according to equation (1). Results are summarized in table 3 and the graphical representation of measured values is depicted in figure 3.

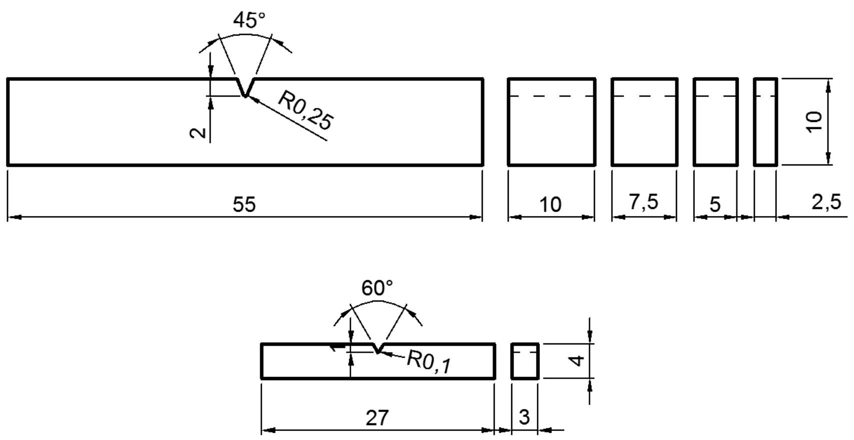

Figure 1. Dimensions of used specimens.[16-17].

$$KCV = \frac{KV}{area\ under\ notch} \quad (1)$$

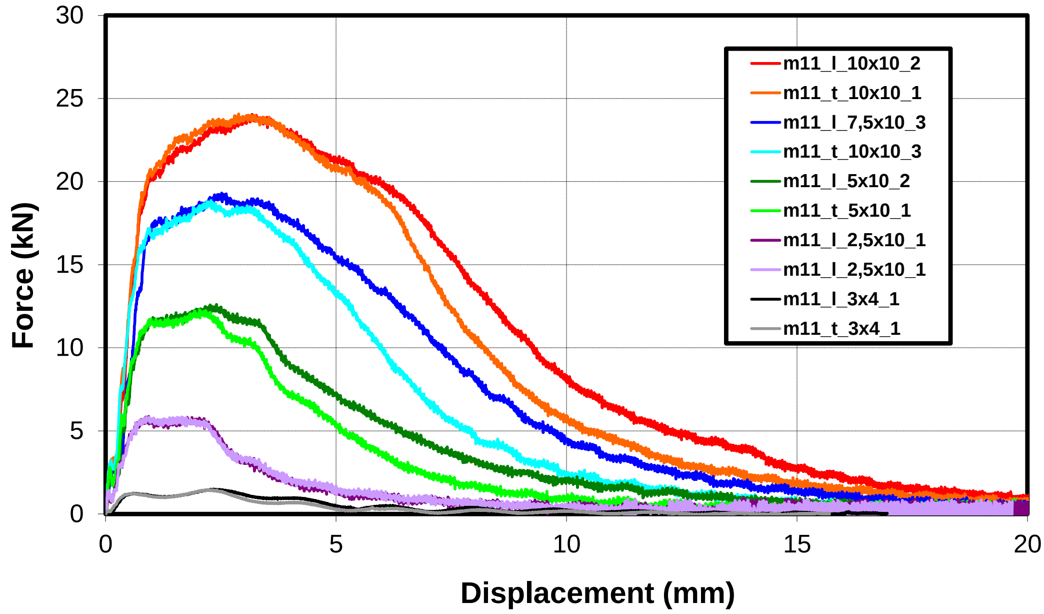

Figure 2. Example of instrumented Charpy records, material m11.

Table 3. Charpy test results.

Specimen Size	AUN	m06		m08	m11		m15	AK1TD
		Long.	Trans.	Long.	Long.	Trans.	Long.	Long.
(mm)	(mm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)
10x10	80	147.1	166.0	203.0	277.8	247.2	111.7	147.6
10x7,5	60				238.6	193.9		
10x5	40			157.1	187.9	148.8		125.9
10x2,5	20			121.7	123.7	114.3		85.3
3x4x27	9	77.4	81.8	99.1	113.9	96.9	62.9	73.4

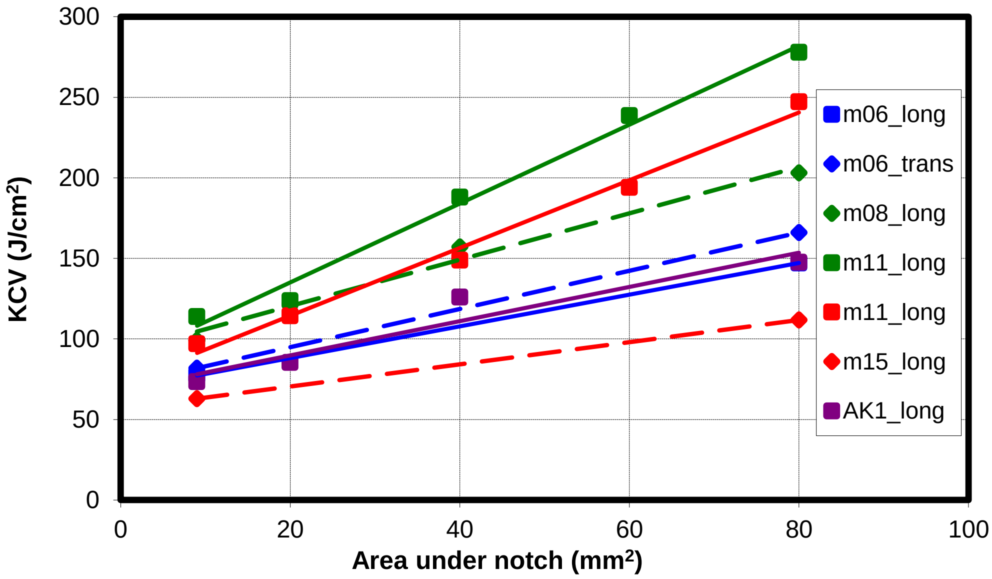

Figure 3. Graphical representation of measured values.

4 Results discussion

Measured data show that notch toughness KCV decreases with decreasing area under the notch (AUN) and therefore with decreasing specimen thickness. As each material has different absorbed energy, KCV value can be normalized using the following equation (2):

$$KCV_{NS} = \frac{KCV_S}{KCV_{10x10}} \cdot 100 \tag{2}$$

Where:

KCV_{NS} is normalized notch toughness of specific specimen size (%),
KCV_S is notch toughness of specific specimens size (J/cm2) and
KCV_{10x10} is notch toughness of full size specimen (J/cm2).

Table 4 summarizes Charpy test results converted to normalized notch toughness. Normalized notch toughness depending on the area under the notch is depicted in figure 4. All KCV_{NS} values are inside the envelope formed by the upper (UL) and lower line (LL) which can be described using equations (3) and (4). Further work will be focused on the verification of these borders for other materials.

Table 4. Charpy test results converted to normalized notch toughness.

Specimen Size [mm]	AUN [mm^2]	m06 Long. %	m06 Trans. %	m08 Long. %	m11 Long. %	m11 Trans. %	m15 Long. %	AK1TD Long. %
10x10	80	100.0	100.0	100.0	100.0	100.0	100.0	100.0
10x7.5	60				85.9	78.5		
10x5	40			77.4	67.6	60.2		85.3
10x2.5	20			59.9	44.5	46.2		57.8
3x4x27	9	52.6	49.2	48.8	41.0	39.2	56.3	49.7

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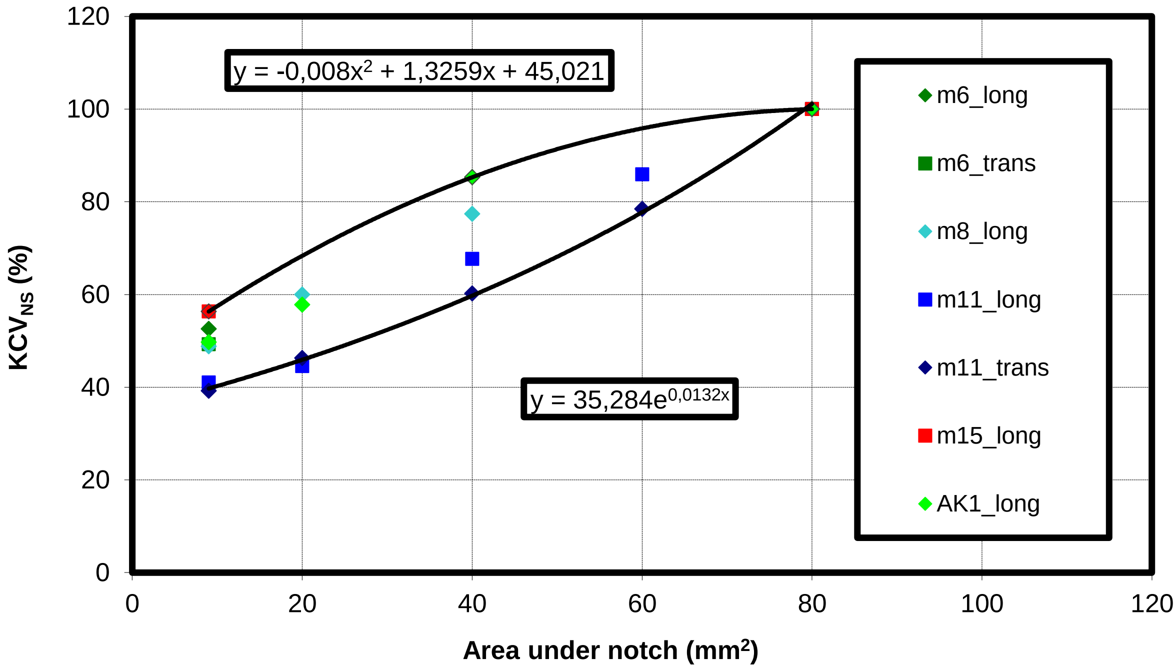

Figure 4. Normalized notch toughness depending on the area under the notch.

$$KCV_{NS/UL} = -0.008 \cdot AUN^2 + 1.3259 \cdot AUN + 45.021 \quad (3)$$

$$KCV_{NS/LL} = 35.284 \cdot e^{0.0132} \quad (4)$$

5 Conclusion

A new approach in correlation from sub-size to standard Charpy test results was proposed. In total, 24 different types of tests were performed with at least three repetitions and therefore more than 72 instrumented Charpy impact tests were performed. Furthermore, for all materials, chemical analyses were performed as well as tensile properties investigation. It can be assumed that the proposed correlation is valid for similar types of material investigated in this paper. However, other materials should be investigated to confirm the general validity of the suggested correlation or, alternatively, to specify its limits.

Acknowledgements

This paper was created by project Development of West-Bohemian Centre of Materials and Metallurgy No.: LO1412, financed by the MEYES of the Czech Republic.

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