Influence of specimen dimensions on ductile-to-brittle transition temperature in Charpy impact test

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Abstract. This paper discusses the correlation between specimen dimensions and transition temperature. Notch toughness properties of Standard Charpy-V specimens are compared to samples with lower width (7.5 mm, 5 mm, 2.5 mm) and sub-size Charpy specimens with cross section 3x4. In this study transition curves are correlated with lateral ductile part of fracture related ones for 5 considered geometries. Based on the results obtained, correlation procedure for transition temperature determination of full size specimens defined by fracture appearance of sub-sized specimens is proposed.

1 Introduction
Charpy test is one of the basic material tests used for material properties characterization. In order to avoid brittle failure under service conditions, transition temperature based on Charpy impact tests is determined for the materials exhibiting transition behavior. The size of the experimental material does not allow in all cases application of standard full size specimens (10x10 mm) and sub-size specimens have to be used. Although, some of sub-sized geometries are standardized, procedures for comparison of results obtained for various specimen geometries are not standardized due to ambiguous relations for different applications. Therefore, relations for specific areas have to be individually established.

The use of Charpy specimen geometry with different dimensions leads to development of correlation procedure of the results. A review of the literature shows the efforts to correlate results for standard Charpy with different width [1,2] and standard Charpy with sub-size Charpy [3-14]. Small specimen method is also used in another mechanical testing techniques [15,16, 17] to minimalize the size of tested material.

The aim of presented work was to study influence of Charpy specimen dimensions on ductile-to-brittle transition temperature. Standard Charpy-V specimens are compared to samples with reduced widths (7.5 mm, 5 mm, 2.5 mm) and sub-size Charpy specimens with cross section 3x4 mm. The paper proposes the correlation procedure for transition temperature determination of full size specimens based on fracture appearance of sub-sized specimens.

2 Experiment description
The fracture appearance transition temperatures (FATT) were investigated for Chromium steel P-AK1TD (10,5% Cr, 1.5-1.8% Ni, 1.6-2% W, 0.35-0.5% Mo). Figure 1 shows the microstructure of the steel investigated.
The tests were performed by using standard Charpy-V and sub-size Charpy specimens. Standardized Charpy-V specimens with various widths (10 mm, 7.5 mm, 5 mm, 2.5 mm) [18] and sub-size Charpy specimens with cross-section 3x4 mm [18], shown on the figure 2, were tested. Impact tests were conducted using a 300 J pendulum with striking edge radius 2 mm for standard specimens and 15 J pendulum with striking edge radius 2 mm for sub-size Charpy.

FATT (FATT 50) were determined for each batch by testing of 18 test pieces. Tests were carried out at about 10 testing temperatures for each batch. Fracture appearance and lateral ductile part thickness, marked x on the figure 3a were determined by microscopic measurements. The x-value was obtained by dividing ductile part area at lateral edges of fracture by its length, as shown in figure 3b.
3 Results and discussion

Figure 4 presents the fracture faces of specimens tested at various temperatures. Results suggest that lateral ductile part thickness - x is similar for all Standard Charpy specimens at the same temperature.

![Figure 4. Fractures of tested specimens.](image-url)

Table 1 and figure 5 present the relationship between temperature and x-thickness for standard Charpy and for sub-size Charpy. These dependences can be approximated by fourth-degree terms shown in the figure 5.

**Table 1.** Measurements of x-thickness for standard Charpy and sub-size Charpy.

| Temperature (°C) | x in standard Charpy (mm) | x in sub-size Charpy (mm) |
|------------------|---------------------------|---------------------------|
| -120             | 0.04; 0.06                | 0.08                      |
| -110             | 0.07                      | 0.07                      |
| -100             | 0.09; 0.11                | 0.07                      |
| -90              | 0.13                      | 0.18; 0.11                |
| -80              | 0.15; 0.16                | 0.16                      |
| -70              | 0.18; 0.20                | 0.16; 0.30                |
| -50              | 0.28                      | 0.41; 0.55                |
| -40              | 0.35; 0.36                | 0.64                      |
| -20              | 0.64; 0.82                | -                         |
| 0                | 1.53; 1.74                | -                         |
Figure 5. Relationship between temperature and x-thickness for standard Charpy and sub-size Charpy

FATT and x-thickness at corresponding transition temperature for each batch of specimens were measured and compared. Results are shown in table 2. Figure 6 presents dependence of FATT on x-thickness for standard Charpy. It was found, that x-thickness at FATT for standard Charpy is linearly proportional to sample width. In other words, fracture appearance transition in this material occurs, when x-thickness is about 8.5% of specimen width.

Table 2. Measurements of FATT and x-thickness in FATT.

| Specimen dimensions (mm) | FATT (°C) | x (mm) | x/W  |
|--------------------------|-----------|--------|------|
| 10x10                    | -17.3     | 0.88   | 0.088|
| 10x7.5                   | -24.4     | 0.66   | 0.088|
| 10x7.5                   | -24.4     | 0.61   | 0.081|
| 10x5                     | -31.6     | 0.46   | 0.092|
| 10x5                     | -31.6     | 0.45   | 0.090|
| 10x2.5                   | -68.3     | 0.20   | 0.080|
| 10x2.5                   | -68.3     | 0.19   | 0.078|
| **Average:**             | **0.085 (8.5%)** | **0.21** | **0.070** |

Figure 6. The dependence of FATT on x-thickness for standard Charpy.
The assumption, that \( x/W \) ratio in FATT is constant for each standard Charpy gives a possibility to approximate FATT based on \( x \)-measurements of specimens with different widths. FATT depends on specimens’ width, which can be calculated from \( x \)-thickness using simple equation (1). Figure 7 shows discussed dependence calculated from \( x \)-thickness measurements (figure 5). The correlations between standard Charpy width and transition temperature can be find in literature [1,2]. Figure 7 confirms, that presented correlation procedure gives similar results to correlations from the literature. Different trends for standard and sub-size Charpy seem to suggest influence of other parameters. Literature [20] confirms effect of notch depth, notch root radius and specimen height on transition temperature appearance, what can be observable at presented chart. The advantage of proposed correlation procedure, comparing to constant correlation curves is a possibility to find the relationship between FATT and specimens width for non-standard Charpy specimens and more precise results for non-standard steel.

\[
W = \frac{x}{\text{average} \left( \frac{x}{W} \right)}
\]

(1)

![Figure 7. Correlations between Charpy width and FATT.](image)

4 Conclusions

The correlation procedure for transition temperature determination of full size specimens based on fracture appearance of specimens with different width is proposed here. The correlation procedure assumes that the thickness of ductile part located on the edges of fracture in fracture appearance transition temperature is proportional to sample width. Using proposed procedure, there is possibility to approximate FATT temperature for each width of standard Charpy. Correlation for sub-size Charpy comparing to standard Charpy suggests the influence of specimens width, height, notch depth and notch root radius on transition temperature.

The advantage of proposed correlation procedure, comparing to constant correlation curves from the literature is a possibility to find the relationship between FATT and specimens width for non-standard Charpy specimens and more precise results for non-standard steel.

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