EFFECT OF SAMPLE GEOMETRY ON TENSILE PROPERTIES OF CHROMIUM ALLOYED MIDDLE CARBON STEEL

Ludmila KUČEROVÁ [1], Štěpán JENÍČEK, Josef MACH [1]

[1] *University of West Bohemia in Pilsen, Regional Technological Institute, Czech Republic, EU*
skal@rti.zcu.cz, jeniceks@rti.zcu.cz, machj@rti.zcu.cz

Abstract

42SiCr steel is a middle carbon, low alloyed steel with (in wt. %) 0.4C, 1.3Cr, 0.6Mn and 2Si. In this work, the steel was used in hot rolled state, possessing bainite-based microstructure. In development and optimization of heat and thermo-mechanical treatments, small volumes of materials are commonly processed in various simulators or dilatometers. This means that smaller samples for mechanical testing are also necessary and question arise how exactly various sample geometries affects measured mechanical properties, particularly ductility. Four types of samples for tensile test were used for the comparison. Three of them were flat, with various cross sections and active lengths of 15, 20 and 50 mm. The same thickness of 1.2 mm was kept for all three types of flat samples. For a reference, a sample with circular cross section with 5 mm diameter and 25 mm active length was tested as well. Zwick Roell Z250 was used to perform tensile tests, according to ČSN EN ISO 6892-1. Six samples of each dimension were tested and used for calculation of average values of tensile properties. Following intervals of tensile properties were obtained: yield strengths of 721-766 MPa, ultimate tensile strengths of 1205 - 1335 MPa and total elongation of 15-19%. The highest elongation was measured for circular samples, while the highest ultimate tensile strength was achieved in the flat sample with active length of 20 mm.

Keywords: Mechanical properties, sample geometry, chromium alloyed steel, middle carbon steel

1. INTRODUCTION

It has been generally known for decades that „size does matter" in tensile tests [1,2]. There is obviously a sample size so small that the grain size, number of grains and representativeness of microstructure distribution in the cross section start to play an important role [3] and this phenomena was called scaling effect [2]. However there is quite a large span of sample dimensions in which tensile strength is believed to be relatively in-sensitive to sample size, while ductility depends strongly on an active length of the sample. This is caused by the combination of ductility being evaluated with respect to the initial sample length and significant concentration of plastic deformation around fracture area. This implies that materials undergoing larger plastic deformation prior to cracking would be more sensitive to evaluated length of the sample. In material research of various advanced high strength steels, there is a strong tendency to minimize the size of testing samples, or more generally to use non-standardized sample geometries. Traditionally, small sample size has been interesting for power plant and nuclear materials, particularly in the area of prediction of future behaviour of materials in working conditions [4, 5]. Sample size decrease is also a natural result of increased use of various simulators and dilatometers which are typically able to ensure precise control of thermal and deformation parameters; however they can process only a limited volume of material [6-8]. The onset of various in-situ characterisation tests, which naturally require smaller samples to fit inside microscope or diffractometer chambers [9], also resulted in increased usage of minimized samples for mechanical testing. In all of these cases, mechanical properties can be safely compared within one workplace which uses the same sample geometry and testing method, however it starts to be more difficult to relate the results obtained by various authors using at various sample geometries. Regional technological institute is facing this problem due to its involvement in research of various grades of high strength steels. To estimate how much this size effect of specific sample types used in recent works of the Institute influence obtained properties of low alloyed steels, experimental comparison was carried out using 42SiCr steel.

2. EXPERIMENTAL PROGRAM

2.1. Material

A middle carbon low alloy 42SiCr steel was used for an experimental program (**Table 1**). The steel was cast and hot rolled in Třinecké železárny. Plates with the dimensions of 170 x 330 mm and thickens 10 mm and were obtained by this processing. The final microstructure possessed the hardness of 390 HV 10 and was predominantly bainitic with martensitic areas and fine sharped-edges islands of ferrite (**Figue 1**). Occasional small areas with very fine pearlite were also observed. This steel has relatively high strength with good ductility in this state; the properties can be further improved by dedicated heat or thermo-mechanical treatment using quenching and partitioning (QP) processing method [10]. Congenital hot-forged state was chosen over the strengthened state for testing due to its higher ability of plastic deformation, which should better reflect potential dependence of ductility on used gauge length.

Table 1 Chemical composition of 42SiCr steel (in wt. %)

C	Mn	Si	P	S	Cr	Ni	Al	Nb	Mo
0.43	0.59	2.03	0.009	0.004	1.33	0.07	0.008	0.03	0.03

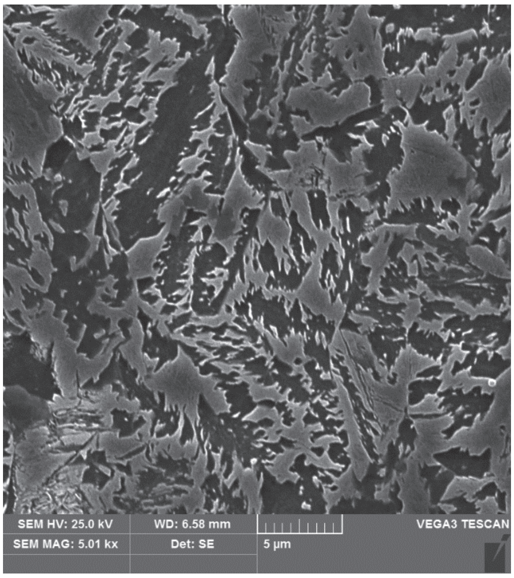

Figure 1 Microstructure of the 42SiCr plates, etched in 3 % Nital

2.2. Geometry of tensile samples and testing conditions

Flat samples of different dimensions (**Figure 2** - **Figure 4**) were prepared from the sheets. Longitudinal axis of all the samples was oriented in the rolling direction. The samples possessed various cross sections and gage lengths of 15 mm, 20 mm and 50 mm. The thickness of all three types of samples was kept 1.2 mm. The shape of all flat samples was cut from the plates by water jet cutter and the body was grinded to the desired thickness.

Long flat sample with gauge length of 50 mm (**Figure 2**) corresponds to ČSN EN ISO - 6892-1, Table B.1, Chapter b.2. Shorter flat sample with a gauge length of 20 mm (**Figure 3**) was designed for testing of thin sheet samples processed at thermo-mechanical simulator and does not confirm to any standard.

Flat sample with a gage length of 15 mm (**Figure 4**) is not proportional in the sense of ČSN EN ISO 6892 and does not correspond to any sample type suggested by standards. It was designed as the shortest sample possible to fit into MTII/Fullam heated in-situ tensile testing stage (**Figure 5**) with cross section small enough to enable tensile test of high strength steels with loading cell of 4500 kN [9].

Reference cylindrical sample with 5 mm diameter and 25 mm gauge length (**Figure 6**) was used to enable comparison of results with those obtained at typical bulk material samples. This geometry corresponds to proportional sample according to ČSN EN ISO- 6892-1, Table D1, Chapter D.2.3.1. Cylindrical samples were lathed from prisms with base dimensions of 10 mm x 10 mm, which were cut from the plates.

Zwick Roell Z250 tensile testing machine (**Figure 7**) was used to perform tensile tests, according to ČSN EN ISO 6892-1, method A, eLc=0.00025 s^{-1}, range 2. Six samples of each dimension were tested and used for calculation of average values of tensile properties. Standard deviation of proof yield strength, ultimate tensile strength and ductility were calculated for all types of samples to provide information about the scatter of measured values for every sample type.

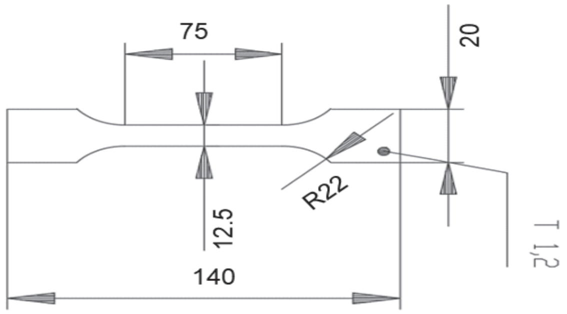

Figure 2 Long flat sample

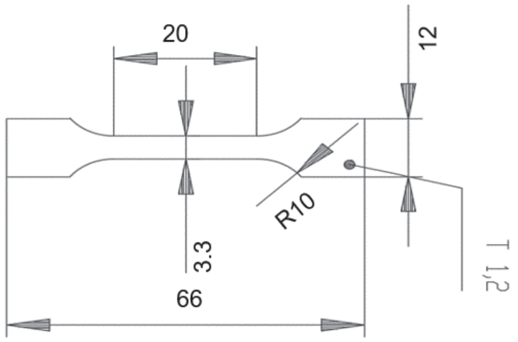

Figure 3 Short flat sample

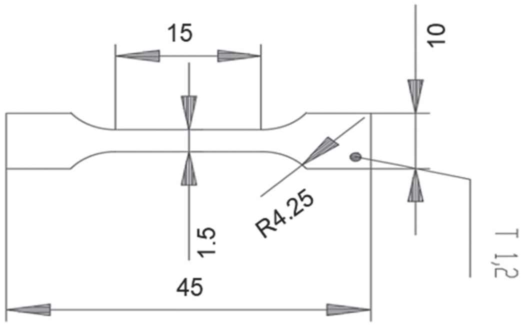

Figure 4 In-situ flat sample (6)

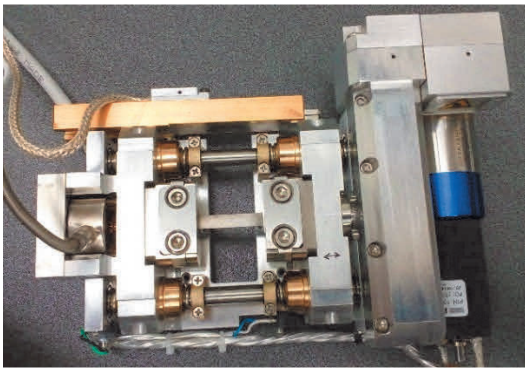

Figure 5 MTII/Fullam stage

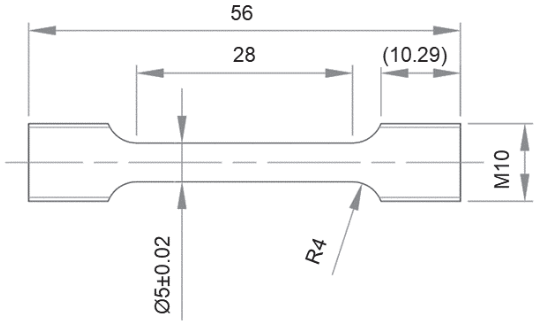

Figure 6 Cylindrical reference sample

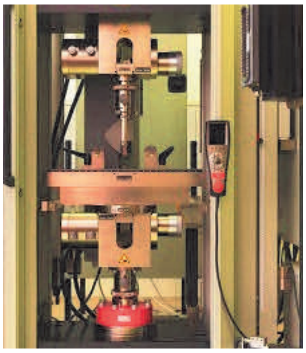

Figure 7 Zwick Roell Z250

3. RESULTS AND DISCUSSION

Average mechanical properties determined from various sample types (**Table 2**) show that differences in yield strengths of all kinds of samples were within 50 MPa, which corresponds to less than 7 % of yield strength value. Ultimate tensile strengths offered larger variety of results, as the difference between the lowest and the highest strength was around 130 MPa, which is around 10 % of tensile strength values. The difference between the lowest and the highest ductility was 3.3 %. Even though it looks like a negligible difference, it is in fact the largest one, as it presents around 19 % of measured ductility. This confirms that ductility is the most susceptible to sample size effect.

Table 2 Mechanical properties and their standard deviations obtained at samples with various geometries (L_0- gauge length, $R_{p0.2}$- proof yield strength, σ- standard deviation, R_m- ultimate tensile strength, A- ductility)

Sample type	L_0 (mm)	Cross section (mm)	$R_{p0.2}$ (MPa)	σ	R_m (MPa)	σ	A (%)	σ
Cylindrical sample	25	5	756	26	1205	101	18.5	2.4
Long flat sample	50	12.5 x 1.2	766	11	1242	12,5	15.2	2.2
Short flat sample	20	3.3 x 1.2	733	62	1332	24	17	1
In-situ sample	15	1.5 x 1.2	712	56	1274	13,5	17	0.7

The highest average tensile strength of 1332 MPa was reached for short flat sample with a gauge length of 20 mm (**Figure 8**). There is no visible relationship between ultimate tensile strength or ductility and the gauge length, not even for flat samples alone. The lowest tensile strength of 1205 MPa was measured at cylindrical sample with a gauge length of 25 mm. It is interesting to note, that this cylindrical sample had by far the highest scatter of measured tensile strengths, which is indicated by its high standard deviation value. Scatter of ductility evaluated from tensile tests of these cylindrical samples was also the highest one; however the highest average ductility of 18.5 % was obtained at the same time. On the other hand, the lowest average ductility was provided by long flat sample, which is in contrast with the general the assumption that longer gauge lengths result in higher ductility.

Proof yield strengths evaluated from various types of flat samples gradually decreased from 766 MPa to 712 MPa with decreasing gauge lengths from 50 mm to 15 mm.

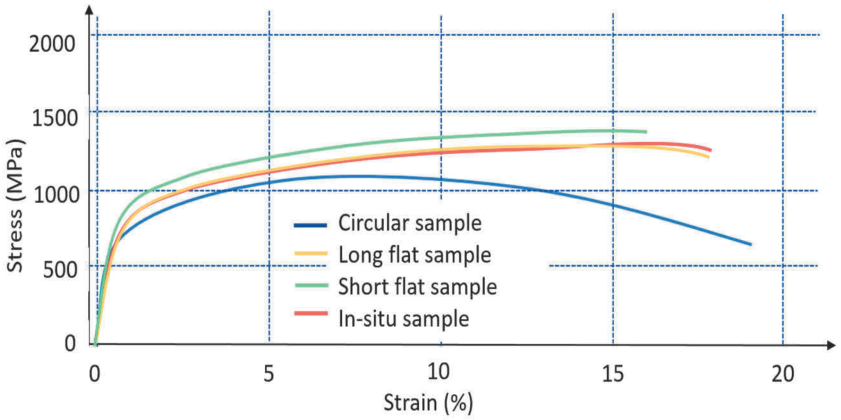

Figure 8 Typical stress-strain curves obtained for various sample geometries

Cylindrical and long flat sample reached the most similar strength values (both yield and ultimate strengths). However, ductilities of these two types of samples were the most different ones and their scatters were also for both sample types higher than for shorter flat samples. On the other hand, long flat samples demonstrated the best repeatability of tensile strength values (the lowest scatters).

4. CONCLUSION

Four types of samples for a tensile test were used to compare obtained mechanical properties of hot forged 42SiCr steel. Three sample types were flat, differing in cross sections and gauge lengths, the fourth sample type had cylindrical body. Two of the samples corresponding to ČSN EN ISO 6892 possessed very similar yield and ultimate tensile strengths. The relationship between tensile strength and gauge length was not observed. The highest tensile strength of 1332 MPa was obtained for flat sample with a gauge length of 20 mm, however shorter gauge length of 15 mm resulted in tensile strength of only 1274 MPa. Average ductility of various sample types did not follow any trend either; the lowest ductility of 15.2 % was obtained for flat samples with the longest gauge length of 50 mm. The same ductility of 17 % was determined for both types of shorter flat samples and they also had relatively low scatter.

It was demonstrated that non-standardized and non-proportional flat samples used in necessary cases for research works, could provide tensile properties comparable to the properties determined using standardized samples and observed scatter of ductility values was in their case even lower that for standardized samples.

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