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ANISOTROPY OF MECHANICAL PARAMETERS OF WELD FOR HIGH-STRENGTH STEEL IN TENSILE TEST FOR TOWING AND COUPLING COMPONENTS IN RECOVERY VEHICLES

Summary. The paper presents results for S700MC high-strength steel and its weld at longitudinal and transverse orientations of specimens. The determination of anisotropy features is proposed for the parent material and welding joint due to the often usage of this steel for manufacturing of towing and coupling components in recovery vehicles. This means that the most important mechanical parameters of the regions questioned should be determined for numerical and analytical analysis with the target to get their type approval and to keep the road safety. The mini-specimens were used to reflect the joint behaviour subjected to monotonic tension. The weld behaviour was assessed using the longitudinal specimen that was manufactured from the joint. The results enabled to indicate differences in the section tested depending on the loading orientations considered.

Keywords: high-strength steel, weld, anisotropy, mechanical parameters, testing

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1. INTRODUCTION

High-strength steel (HSS) is regarded as a modern structural material for various engineering applications because it reflects attractive mechanical parameters such as yield stress (min. 600 MPa), ultimate tensile strength (min. 1300 MPa) and ductility (min. 15%) if compared to other structural materials [1], [2], [3]. HSS can also be characterised by a lower mass in comparison to the conventional structural materials [4], [5]. As a consequence, this steel is recommended to various branches of industry [1], [4], [5], [6]. Among them, one can indicate:

a) machine industry (components of machines for building: excavator bucket, scoops, grabs),
b) automotive (container trailers, flatbed trailers, box trailers, bulk and tank trailers, car carriage trailers, buses and light trucks, concrete pump cranes, mobile cranes, cargo handlers),
c) forest and agricultural (timber trailers, harvesters, forwarders, tippers and trailers),
d) ocean energy (wave energy, tidal and stream energy converters, offshore wind farms),
e) marine mining (jack-u legs and pylons),
f) recovery marine (boom parts, joints and knees, winch equipment).

Fig. 1. The coupling zone made of the S700MC high-strength steel

Typical applications of the S700MC steel for the coupling regions (Fig. 1) and supports for the towing booms used in recovery vehicles are presented in Fig.1 and Fig. 2, respectively.

A wide range of the S700MC steel applications is strongly dependent on the mechanical resistance of a weld on the loading type used, [7], [8], [9]. Therefore, the basic mechanical parameters such as yield point (YP) and ultimate tensile strength (UTS) should be determined as the first step of the experimental procedure. The steel manufacturers indicate many important aspects and parameters of welding, that play an important role, taking into account the joint quality [7], [8].

They should be determined within the temperature range from 500 ^{o}C to 800 ^{o}C executed in a period from 5 to 25 seconds. A value of the period depends on the steel grade. In the case of the S1300MC steel, for example, it is equal to 15. Applying optimal cooling time intervals, higher values of mechanical properties can be obtained. Such procedure is strongly recommended for different welding processes, i.e.: MAG (Metal Active Gas), MMA (Manual Metal Arc), TIG (Tungsten Inner Gas) as well as SAW (Submerged Arc Welding) (SSAB), [7], [8].

Fig. 2. Support of a towing boom body made of the S700MC high-strength steel for the recovery vehicle

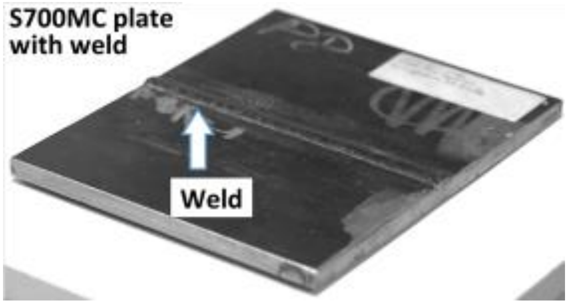
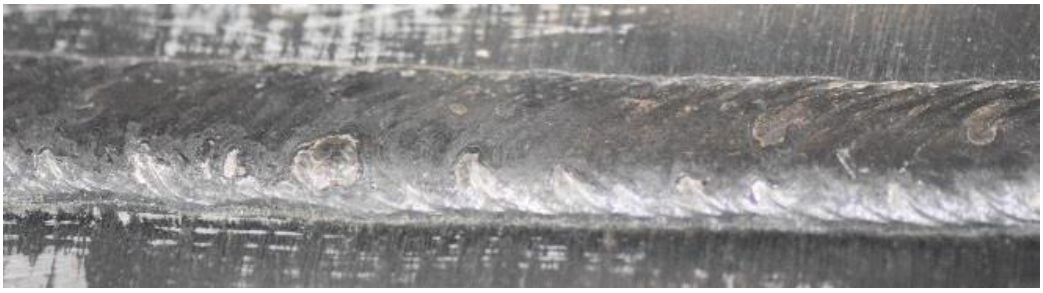
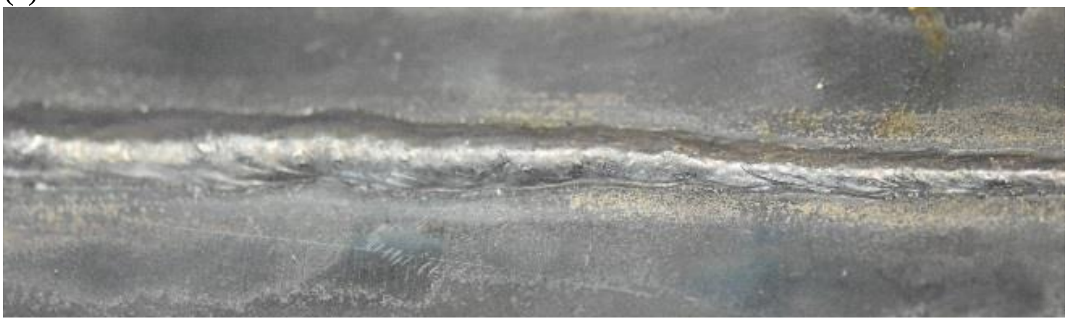


Fig. 3. The S700MC high strength steel plate with a weld

Among many important issues related to mechanical parameters, the determination one can indicate a quality of the welding joint materials reflecting their anisotropic character of either the parent material or weld sections. Many aspects of the majority of the research works in such context have not been thoroughly studied yet. Therefore, in order to fill this gap, the S700MC steel was selected as the object of tests, Figs. 3 and 4.



(a)



(b)

Fig. 4. The S700MC high-strength weld: face (a) and root (b) of the weld, respectively

2. DETAILS OF EXPERIMENT

The S700MC steel with a weld in the form of a plate of 10 mm thickness was tested, Fig. 3.

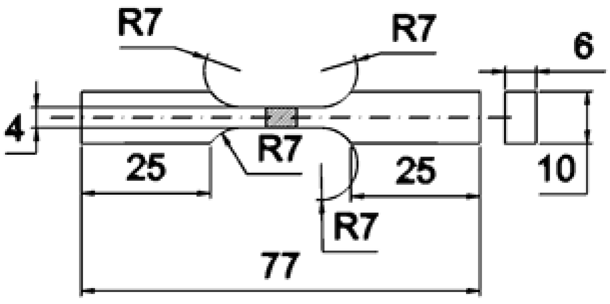


Fig. 5. Mini-specimen used for the parent material and its weld testing under monotonic tensile conditions

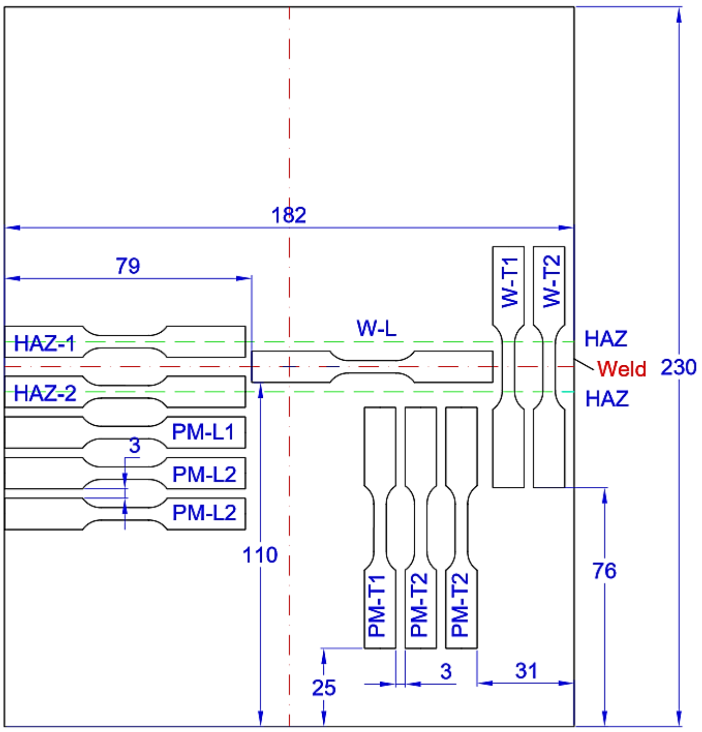
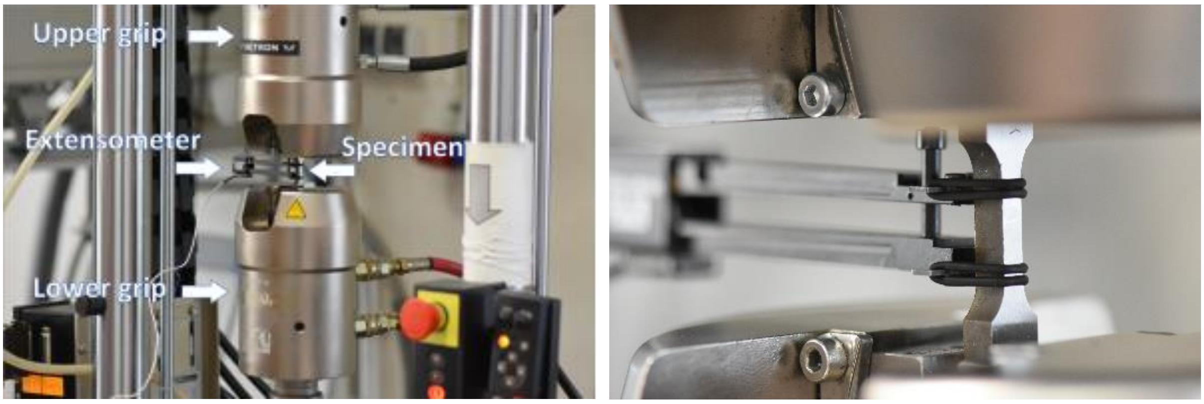


Fig. 6. The specimens' arrangements in the S700MC plate with a weld

The joint was manufactured, Figs. 3, 4, under the following welding parameters (MAG): 175 A and 20 V for remelting, 178 A and 24 V for joint filling under current pulsation within the range of 5.6 – 8.2 m/min.

A flat mini-specimen was designed for testing the parent material and weld, Fig. 5. The specimens were arranged taking a major axis of the weld as the reference axis to produce specimens along longitudinal (L) and transverse (T) directions, Fig. 6.

Therefore, the specimen for examining the weld was manufactured from the region entirely composed of it. The testing of the Heat Affected Zone (HAZ) was carried out on specimens situated in parallel to this area, Fig. 6.



(a) (b)

Fig. 7. Mini-specimen in grips of the 8874 Instron servo-hydraulic testing machine before a tensile test: (a) general view, (b) specimen and 2620-601 Instron uniaxial extensometer

All specimens containing the weld were mechanically processed by removing the face and root. The specimens were directly mounted in the grips of the 8874 Instron servo-hydraulic testing machine, Figs. 7, 8. The values of axial strain were captured using a 2620-601 Instron uniaxial extensometer of gauge length equal to 12.5 mm and measuring capacity of ± 5 mm, Figs. 7a, b. All tests were carried out at room temperature for a displacement velocity equal to 1 mm/min up to the specimens' fracture, Fig. 8.

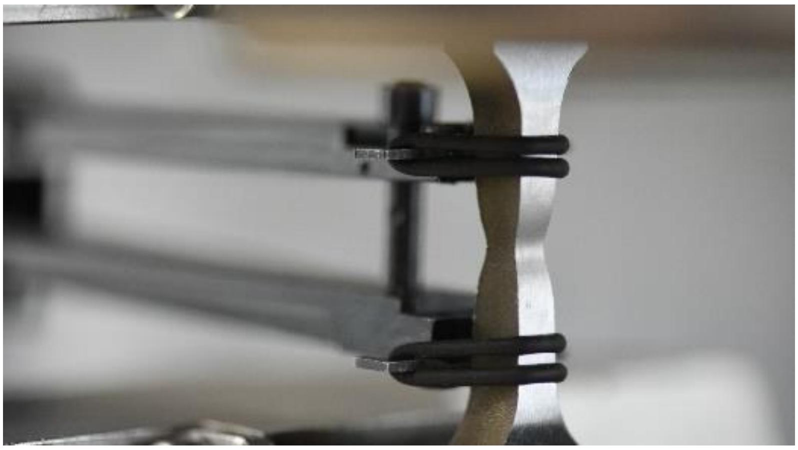


Fig. 8. Mini-specimen made of parent material (the S700MC steel) from transversal direction to the weld's major axis before the final stage of tensile test

3. RESULTS

Data collected during the tensile tests of the parent material were carried out on the specimens taken from either the transverse or lateral directions, Fig. 6.

It has to be emphasized that quite good similarity can be easily observed of both tensile characteristics, Fig. 9. One can conclude that the material exhibited almost isotropic behaviour, and therefore, the manufacturing process applied to the material production can be treated as good enough in terms of ensuring uniform mechanical parameters of the manufactured semi-finished product.

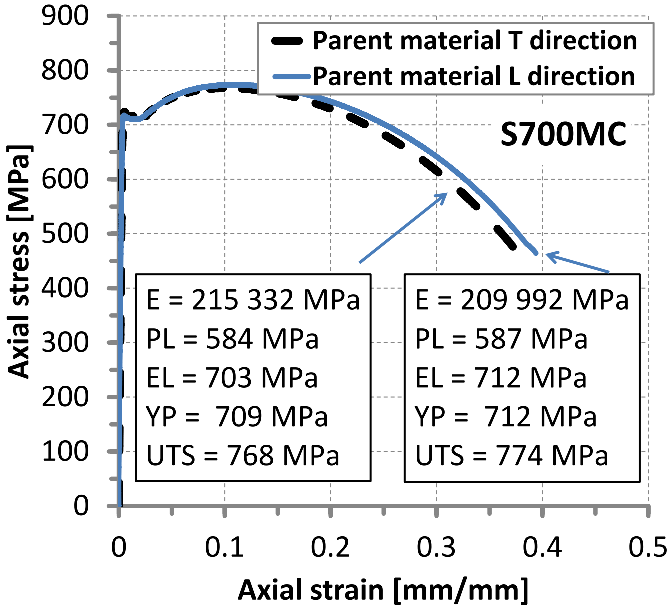


Fig. 9. Tensile characteristics of the parent material selected from both directions, i.e. longitudinal (L) and transverse (T), E – Young's modulus, PL – proportional limit, EL – elastic limit, YP – yield point, UTS – ultimate tensile strength

An opposite effect was for the parent material and weld, Figs. 10, 11. Both tensile characteristics differ significantly. In the case of weld material, the physical yield point disappeared. For the transverse direction (Fig. 11) due to the weld position, besides the clear mechanical parameters' reduction, the tensile curve is located much lower than that for the parent material of the same orientation. Also, a 50% reduction of elongation can be observed, Fig. 11.

The results for the HAZ and weld are presented in Fig. 12. One can easily notice that the behaviour of the weld material depends strongly on the specimen orientation. For the same specimen orientation, the tensile curves were very similar for both the HAZ and weld material (the longitudinal direction).

If directions of the specimens representing HAZ and weld materials are perpendicular (Fig. 12), then the tensile curves take a completely different shape, thus identifying the anisotropic character of the mechanical properties of the welding joint material. This is reflected by the lower values of mechanical parameters and ductility at 13% and 50%, respectively. As a consequence, a high-strength component behaviour with weld should be numerically modelled using lower values of mechanical parameters than the parent material.

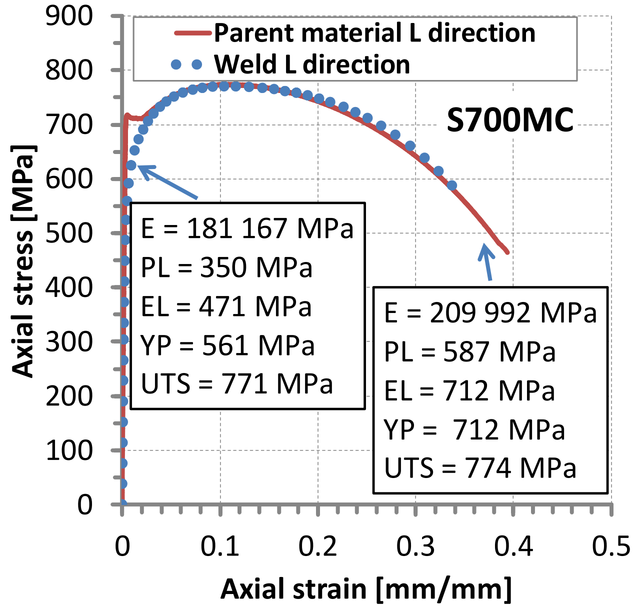


Fig. 10. Tensile characteristics of the parent material and its weld determined using specimens selected from the longitudinal direction

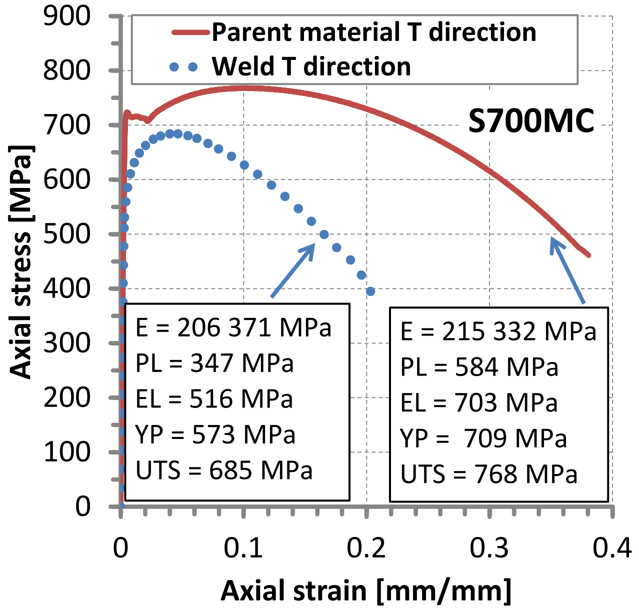


Fig. 11. Tensile characteristics of the parent material and its weld determined by means of specimens selected from the transverse direction

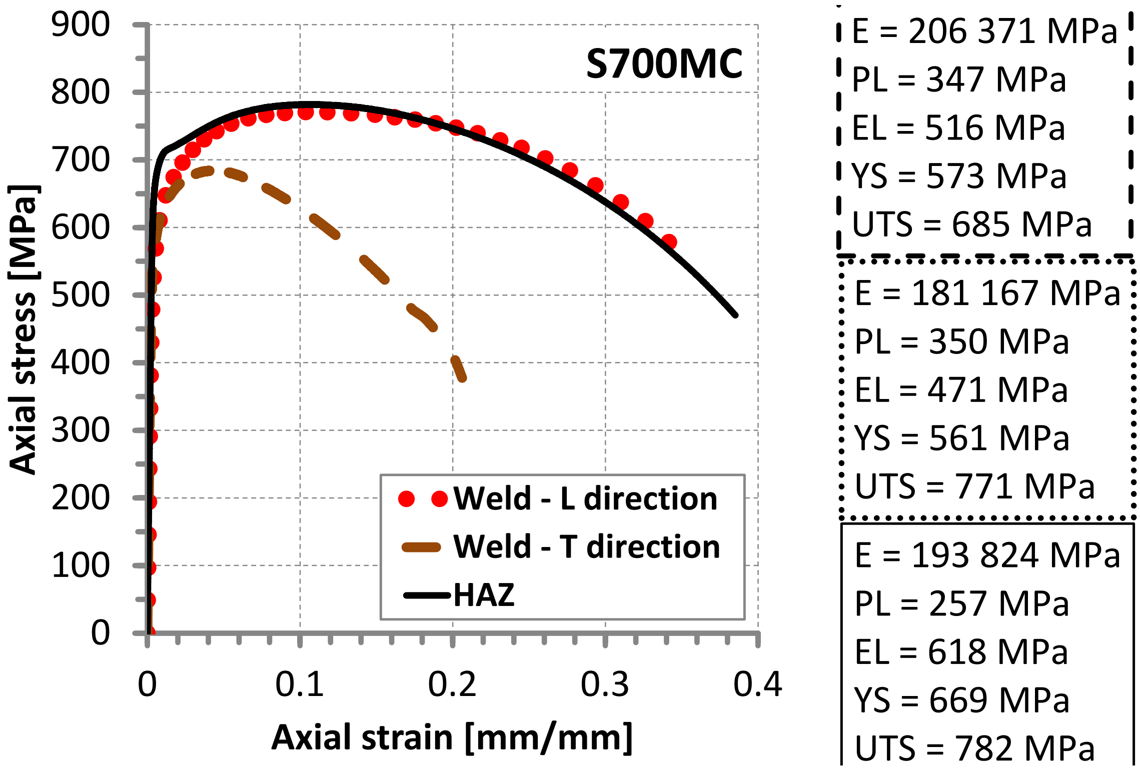


Fig. 12. Tensile characteristics of the weld and HAZ

The anisotropy features were also analysed in the form of power law equations, Tab. 1. This approach has enabled indicating the same values of strain hardening exponent for the parent material, HAZ and weld material. This means the hardening of the material regions examined under tension is represented by very similar deformation mechanisms. It can be easily noticed as the advance of the joining process concerning the steel examined. The second coefficient of power of law, representing stress, indicates that the lowest mechanical resistance is observed for the weld material in the transverse direction.

Tab. 1

Power law equations: PM-parent material

PM-L	PM-T	HAZ	Weld-L	Weld-T
$1096.69\,\varepsilon^{0.11}$	$1074.34\,\varepsilon^{0.10}$	$1109.54\,\varepsilon^{0.11}$	$1113.71\,\varepsilon^{0.12}$	$974.46\,\varepsilon^{0.09}$

From a practical point of view, it is worth noticing that this kind of data supports designing components such as platform, working frame and towing booms with coupling functions, for the requirements of UN Regulation 55 (UNR55) [10], which reflects the mechanical resistance of coupling components under cyclic loading. This means the fatigue limit of a weld should be known because this region is very often indicated as the weakest one, and it is inspected after 2×10^6 cycles using dye-penetrant and macrophotography techniques for the regimes of UNR55.

The experimental program was supplemented by analysis of the fracture regions. Differences were represented by fracture regions' orientation, Fig. 13. In the case of the parent material (Figs. 13a, b), despite the high similarity of the tension curves (Fig. 9), there was a difference in the share of stress components involved in the material decohesion. For a longitudinal direction (Fig. 13a), axial stress was dominant for fracturing while in the case of perpendicular one (Fig. 13b) axial and shear components occurred significantly.

The weld and HAZ degradations were very similar concerning the fracture region inclination, i.e. axial stress has followed the process, Fig. 13c, d. Certain differences in the fracture regions of the weld (Figs. 13c, d) and HAZ (Fig. 14) were observed on the direct observation of the fracturing details on the decohesion plane. In the case of the weld, the fracture zones were represented by horizontal and tangential fracture planes, Figs. 14c1, d1 without any cracks – oppositely to the HAZ degradation, Fig. 15.

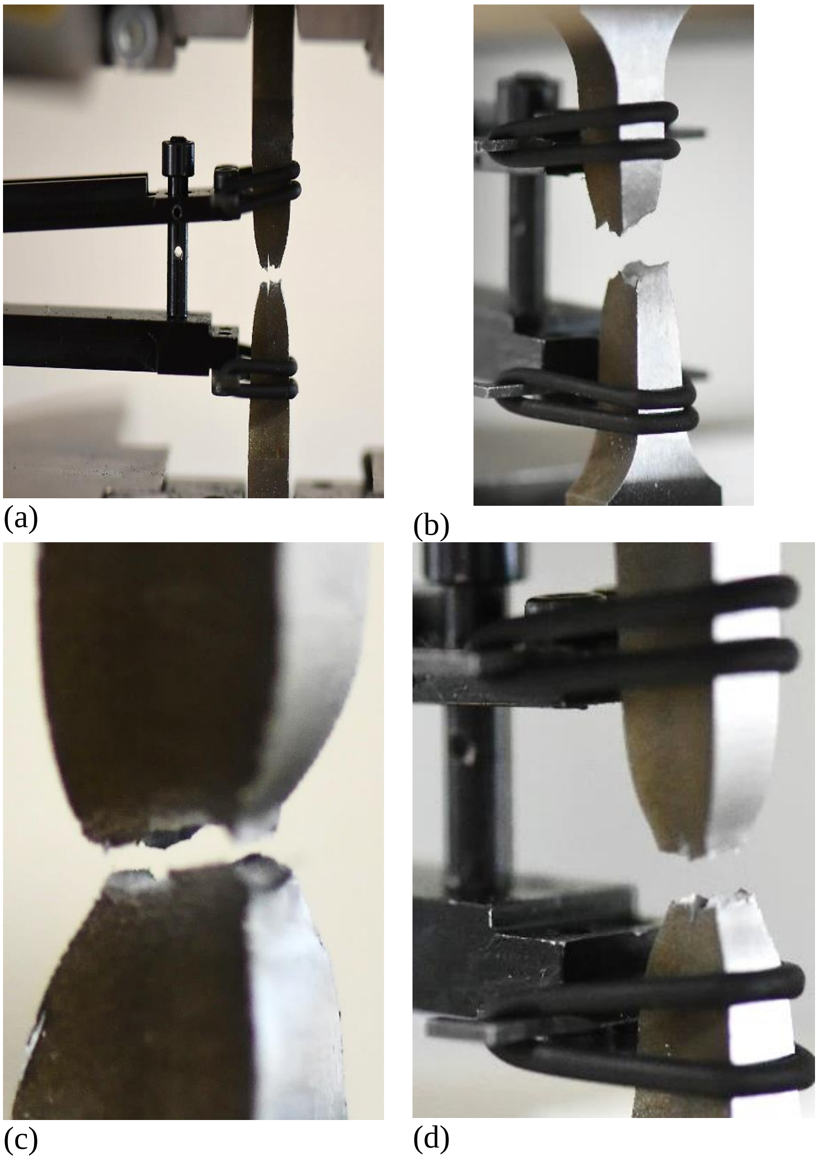


Fig. 13. Specimens after decohesion in tensile test: (a) and (b) parent material and weld in L direction - respectively, (c) weld in T direction, (d) HAZ

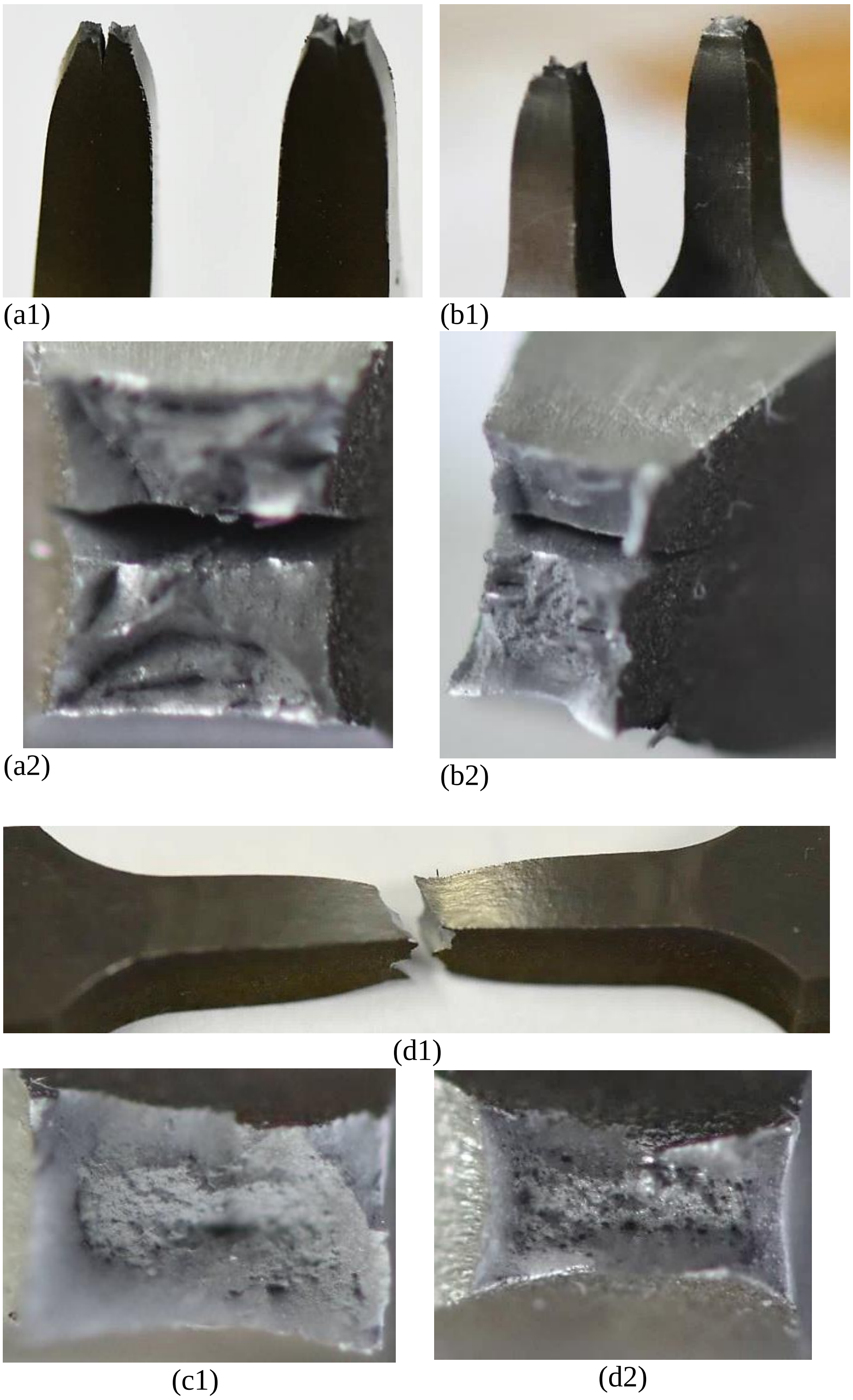
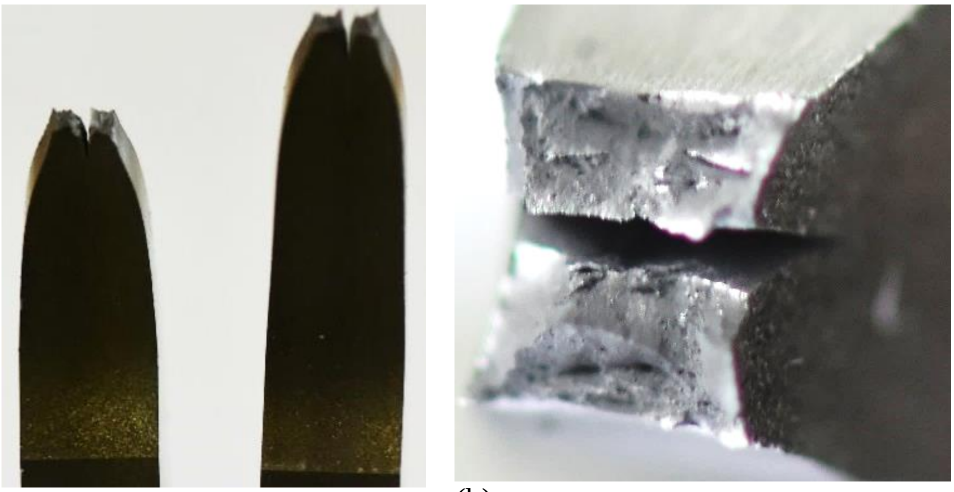


Fig. 14. Fracture zones of the parent material and weld; the parent material in (a1, a2) longitudinal and (b1, b2) transverse directions; the weld in (c1) longitudinal and (d1, 2) transverse direction



(a) (b)

Fig. 15. Fracture zones of the HAZ

Moreover, it is worth noticing that in the case of weld, instead of cracks, small dimples and bi-planar cracking regions were discovered, Figs. 14c1, d2. The HAZ fracture (Fig. 15b) was very similar to that obtained for the parent material, Figs. 14a2, b2. They indicate a small influence of the MAG on the HAZ zone.

In comparison to the SSAB welding requirements of the S700MC, the HAZ should represent the soft zone [11].

The results captured in this research enable formulating a general conclusion that the MAG process used for the welding process of the S700MC steel led to the elimination of the physical yield point for all regions of the joint examined, and as a consequence, enforced necessity for introduction of the proof yield.

4. CONCLUSIONS

The quality of the welding joint should be determined using specimens selected from longitudinal and transverse directions concerning the weld, as well as its heat-affected zone and welded material.

Anisotropy features of a welded region enable indicating the weakest zone of the joint. Hence, the real values of mechanical parameters can be applied for calculations, modelling and designing components for the automotive industry.

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