PLASMA WELDING OF HIGH CARBON STEEL AFTER SPD PROCESS

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Abstract

The methods of intensive plastic deformation SPD (Severe Plastic Deformation) belong to a group of very attractive means of increasing utility properties of metallic materials (strength and structural characteristics). The paper is focused on experimental verification of weldability of high-carbon steel C55E processed by the SPD DRECE (Dual Rolling Equal Channel Extrusion) process. Within experimental works, test welded joints were made from the C55E steel with the use of 15-PAW single or double weld thermal cycle. A test of basic mechanical properties, metallographic examination and an analysis of residual stresses were performed on these joints. Acquired results show that the choice of an appropriate technology and the optimization of welding parameters and thermal cycles allow to achieve solid welds even in the case of materials rather difficult to weld. The optimized welding process does not significantly degrade the properties acquired by SPD.

Keywords: plasma welding, weldability, high-carbon steel, residual stress, severe plastic deformation

1. INTRODUCTION

The use of SPD processes is one of the current trends in development of new materials or enhancing their utility properties. In order to use the processes in industry applications it is necessary to solve a variety of material and technological issues. These include notably the decrease in plastic properties of the material or the issue of developing suitable welding technology for cases in which it is not possible to produce the final component during the SPD process itself. The use of considerate joining technologies such as bonding or brazing is significantly limited by the maximal working temperature and shape of the joint. When using welding it is necessary to choose technologies with a minimal thermal influence on materials and a maximal concentration of heat in the impact track. In case of fusion technologies of welding these include in particular the use of laser beam welding, electron beam welding, and plasma arc welding. The paper presents the results of the use of plasma arc welding in welding the C55 high carbon steel.

2. EXPERIMENTAL MATERIAL AND PROCEDURES

As an experimental material, we used steel strips made from high-carbon steel measuring 48x2x1000mm, which were labelled C55E (12060 according Czech standard). Further on, we selected the PAW-15 welding technology (according ČSN EN ISO 4063). In previous experiments we was also successfully used GTAW-141 welding process [1].

2.1 Experimental material

The chemical composition and default mechanical properties are shown in tables 1 and 2. Each strip had different utility properties, which were put through multiple processing by the DRECE technology. More detailed data about technological parameters of the applied DRECE technology, attained mechanical properties and structure are given in [1-3]. To create test joints, we used a 48x2x200mm strip in a default state and after being processed six times by the DRECE technology.

Table 1. Chemical composition of the high carbon steel C55E.

Steel	C [wt.%]	Si [wt.%]	Mn [wt.%]	Al [wt.%]	P [wt.%]	S [wt.%]
C55E	0,53	0,03	0,43	0,02	0,030	0,035

Table 2. Mechanical properties of the high carbon steel C55E initial state (IS) and 6xDRECE.

Steel C55E	R_m [MPa]	$R_{p0,2}$ [MPa]	A_{80mm} [%]	HV10
IS	549	373	21,1	176
6xDRECE	629	553	9	215

2.2 Weldability high carbon steel

The used C55 steel is not commonly designed for welding. With respect to its chemical composition, most notably the carbon content, it belongs (according to [4]) to high carbon steels with difficult weldability. The material is prone to most types of crackings, especially to both cold and hot crackings. Using regular arc welding technologies would require preheating, reheating and subsequently heat treatment. To avoid these measures it is essential to use a low carbon technology with high heat concentration in the impact track such as laser beam, electron beam and plasma arc technologies.

2.3 Welding technology and procedure

In order to minimize the degradation of material processed by the SPD technology, we chose the plasma arc welding technology (15-PAW). Plasma technology was selected because of its advantages in particular: higher welding speed, excellent quality seam welding as no filler material, a small HAZ and distortion. Welding filler material was not used. As a protective gas and the plasma gas was used with argon flow of 7 l/min. The plasma welding type and used welding parameters are shown in tab. 3 and 4. Fig. 1 shows the weld joints default state and after a sixfold DRECE treatment.

Table 3. Plasma welding type.

	Current [A]	Thickness [mm]
Micro plasma welding	0,05 – 20	0,01 – 3
Medium-plasma welding	20 – 100	3 – 10
Keyhole welding	above 100	10 – 30

Fig. 1. Welded samples. (1,2-after 6xDRECE,3,4-IS)

Table 4. Samples welding parameter.

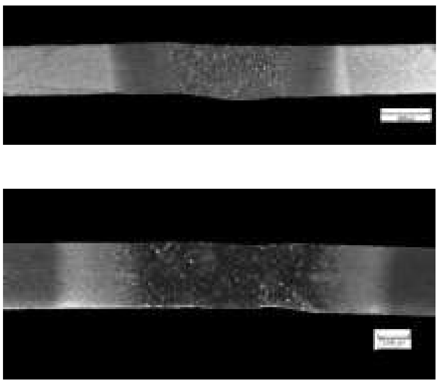
Samples	SPD process	Number of cycles	Welding current [A] 1st cycle/2nd cycle	Welding speed [cm/min] 1st cycle/2nd cycle
1	6xDRECE	2	65/61,5	6,4/14,4
2	6xDRECE	1	65/-	6,4
3	raw	2	60/61,5	6,4/14,4
4	raw	2	60/61,5	6,4/14,4
5	raw	1	65/-	14,4
6	raw	1	65/-	14,4
7	raw	1	65/-	14,4
8	raw	1	65/-	14,4
9	6xDRECE	2	65/61,5	14,4/14,4
10	6xDRECE	1	65/-	14,4
11	6xDRECE	2	65/61,5	14,4/14,4

3. WELDED JOITS PROPERTIES SAMPLES

We performed non-destructive and destructive tests on the control weld joints. The NDT testing consisted of a VT visual control and a PT penetration test according to the ČSN EN ISO 9712. We did not detect any inadmissible indications. Destructive tests included metallographic tests of both macro and micro structure, micro-hardness, tensile test and measurement of residual stresses by the magnetoelastic method.

3.1 Metallographic tests

Fig. 2 shows the macrostructures of weld joints no. 4 (default state) and no. 9 (after a sixfold treatment by the DRECE technology). No defects such as crackings, lack of fusion were detected. Fig. 3, 4 show the microstructure of the weld metal samples no. 4 and 9. A coarse-grained martensitic structure was identified in the weld metal. Fig. 5, 6 show the structure in the zone of overheating in given samples. The structure in sample no. 4 (default state) was martensitic, while a coarse-grained ferrite-pearlite structure was identified in sample no. 9 (sixfold DRECE treatment). In the zone of normalization, a ferrite-pearlite structure with fine grain and globular inclusions was detected in sample no. 4, while sample no. 9 revealed a fine grain structure of ferrite and lamellar pearlite. In general it is possible to conclude that in weld joints of steel treated by SPD process, a finer grain structure in HAZ was attained and the HAZ proportions were significantly smaller.



a)

b)

Fig.2. Macrostructure PAW sample-IS no.4 (a) and 6xDRECE sample no.9 (b).

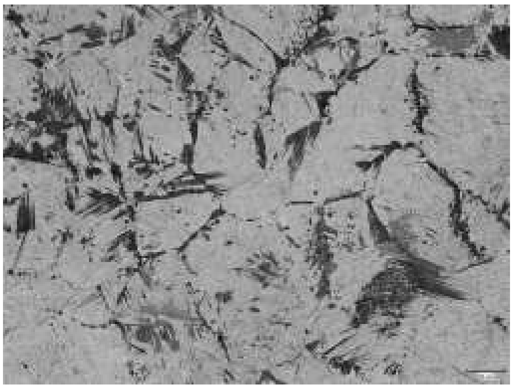


Fig.3. Weld metal microstructure sample no.9, Nital etched.

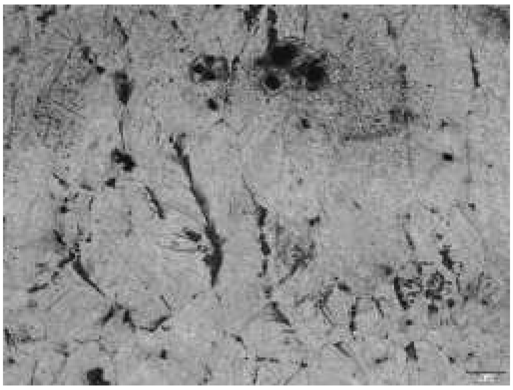


Fig.4. Weld metal microstructure sample no.4, Nital etched.

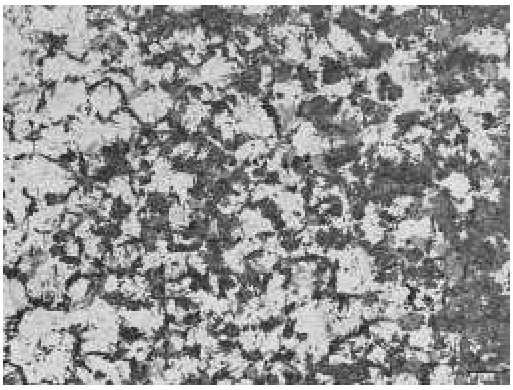


Fig.5. HAZ-grain growth zone sample no.9, Nital etched.

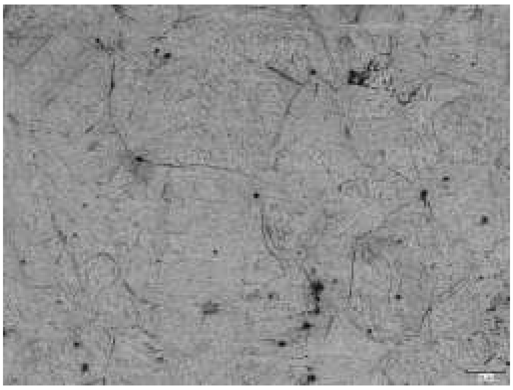


Fig.6. HAZ-grain growth zone sample no.4, Nital etched.

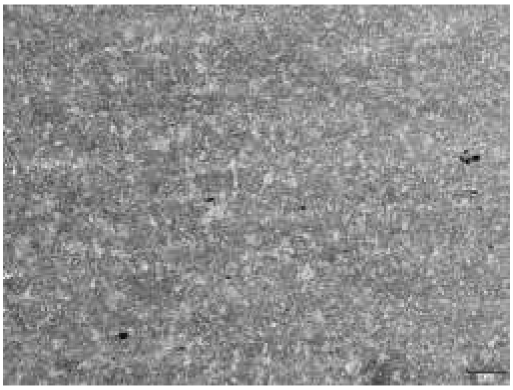


Fig.7. HAZ-recrystalization zone sample no.9, Nital etched.

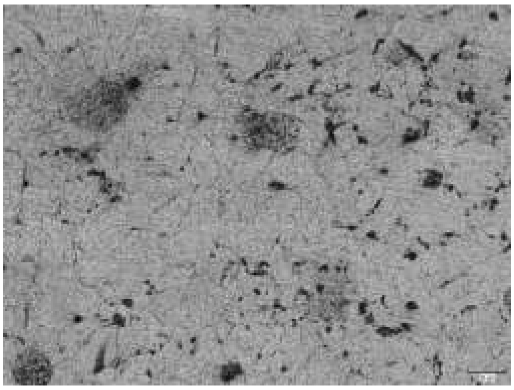


Fig.8. HAZ-recrystalization zone sample no.4, Nital etched.

3.2 Residual stress analysis

We conducted an analysis of residual stresses on selected materials using the magnetoelastic method. A similar characteristic of methods of residual stress measurement and the characteristic of the magnetoelastic method are included in lit. [6-10]. Method utilized changes the Barkhausen magnetic noise in stress field. On acting magnetic field on material an orientation change of Weiss do-mains comes about. In a coil surrounding magnetized metal these changes manifest themselves like current impact. These current impacts can be observed acoustically like so called Barkhausen noise. Samples no. 2, 4, 7 and 9 were selected for an analysis of residual stresses. Residual stress was analyzed perpendicular to the joint axis in the sample axis. In order to preserve maximal resolution, the values of magnetic parameter (MBN) were not converted to stress values in MPa. With given settings of the measuring equipment, it is possible to set the tensile stress over 300 MBN. Below 300 MBN the stress is compressive. Fig. 9 shows a typical residual stress course in a weld joint with tensile maximums in HAZ. The treatment by SPD process brings into the material beneficial residual stress, which does not change even during welding by one or two welding cycles – see fig. 10.

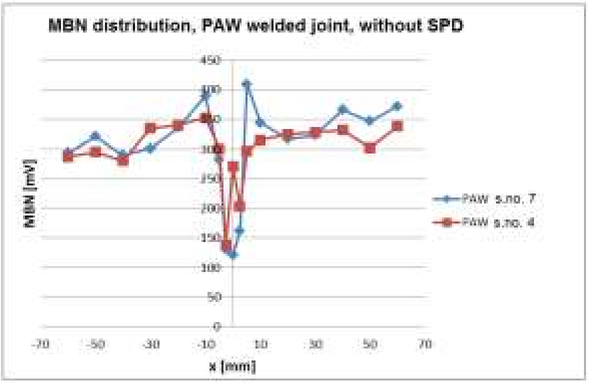


Fig. 9 Graph of the MBN distribution, initial state, centre strip, sample no.7 and 4.

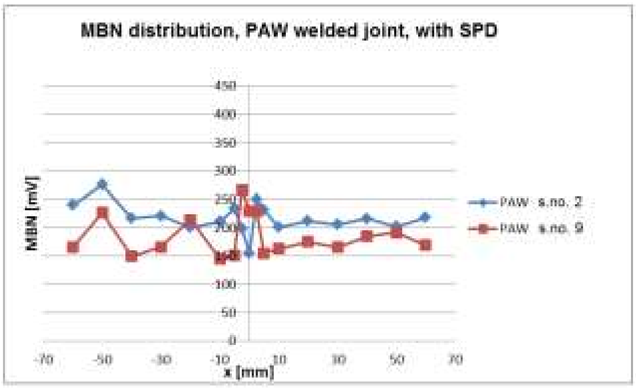


Fig.10 Graph of the MBN distribution, six time DRECE, DRECE, centre strip, sample no.2 and 9.

3.3 Tensile test of welded joints

Samples no. 1, 3, 5, 6, 8 and 10 were selected for the analysis. Before the test, the samples were adjusted to proportions 30 x 220 mm (see Fig. 11). An I joint without weld area modifications was selected. Recorded values are shown in table 5. In case of all samples except sample no. 1, fractures in the weld metal occurred. In case of sample no. 1, the fracture was in the default material (see Fig.12.). The transfer of heat from welding to the processed material by SPD technology did not substantially affect the plastic properties of materials, which are relatively low.

Table 5. Tensile test of welded joints-results.

Samples	Rm [MPa]	$R_{p0,2}$ [MPa]	A [%]	Fracture location	$R_{p0,2}$/Rm
1	547	454	1,3	base material	0,83
3	461	301	5,8	weld	0,65
6	405	354	1,7	weld	0,87
8	398	375	0,9	weld	0,94

Fig.11 Tensile test samples.

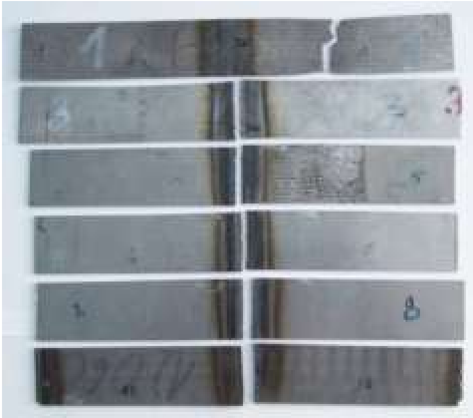


Fig.12 Tensile test samples after fracture.

CONCLUSION

The paper describes the results of plasma arc welding of the C55 high carbon steel in a default state and after a sixfold treatment by the SPD DRECE technology. Based on the conducted measurements, it is possible to infer the following conclusions. Even though the steel is a difficultly weldable material, solid and undivided weld joints were achieved. The DRECE technology brings into the material tensile residual stress, which very positively affects the overall weldability of a given material. Most notably, the grain becomes finer and a smaller HAZ is created. The welding thermal cycle did not substantially affect the relatively low plastic properties characteristic of SPD processes. In case of welding application it shall be suitable to use (instead of an I joint) a lap joint, which should guarantee higher strength of the joint and potential disruption outside the weld area.

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