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Weldability of carbon steel processed by multiple plastic deformation

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ABSTRACT

Purpose: 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.

Design/methodology/approach: A test of basic mechanical properties, metallographic examination and an analysis of residual stresses were performed on these joints.

Findings: Acquired results show that the choice of an appropriate technology and the optimization of welding parameters 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.

Research limitations/implications: Mastering a proper coupling technology, welding materials after plastic deformation in particular, is one of key parameters for a successful application of given materials in technical practice. Within experimental works, test welded joints were made from the C55E steel with the use of 141-GTAW pulse welding technologies.

Originality/value: 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).

Keywords: Weldability; High-carbon steel; Residual stress; DRECE; Severe plastic deformation

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PROPERTIES

1. Introduction

One of the current trends in the development of new materials is increasing their utility properties through cyclic plastic deformation. One of the technological variants tested at the Department of Mechanical Engineering, VŠB TUO is the DRECE (Dual Rolling Equal Channel Extrusion) technology [1,2]. Production of materials with high utility properties itself does not guarantee their further use in technical practice. In order to achieve successful application, it is necessary to solve the issue of subsequent further processing of given materials into their final state, so that the following technological process (welding or machining) does not degrade acquired high utility properties. Welding is one of the primary technologies used to conjoin metal materials; further on, it has a decisive effect on the resulting quality of material. Only an appropriately designed technology enables minimal degradation of welded materials.

2. Experimental material and procedures

As an experimental material, we used steel strips made from high-carbon steel measuring 48x2x1000 mm, which were labelled C55E (12060 according Czech standard). Further on, we selected the GTAW-141 welding technology in a pulse mode as an appropriate welding technology. Alternatively, the PAW-15 technology is also considered.

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 [2,3]. To create test joints, we used a 48x2x200 mm strip in a default state and after being processed six times by the DRECE technology. Considering the chemical composition, a higher content of carbon in particular, and the susceptibility to hardenable structure, it is vital to carefully select the thermal regime of welding. Figures 1 and 2 show the CCT diagram and hardenability diagram for the C55E steel according to [5].

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

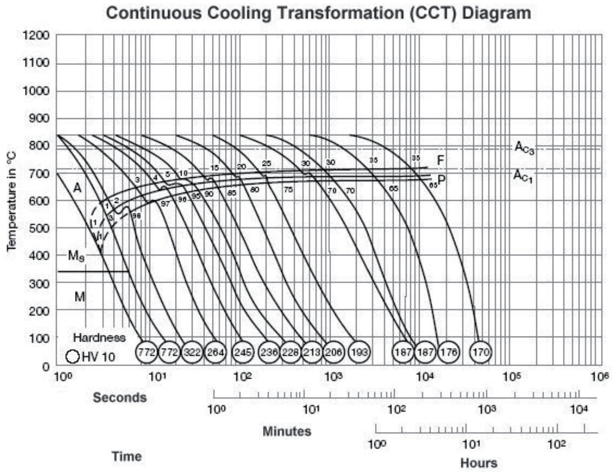

Fig. 1. CCT diagram C55E steel [5]

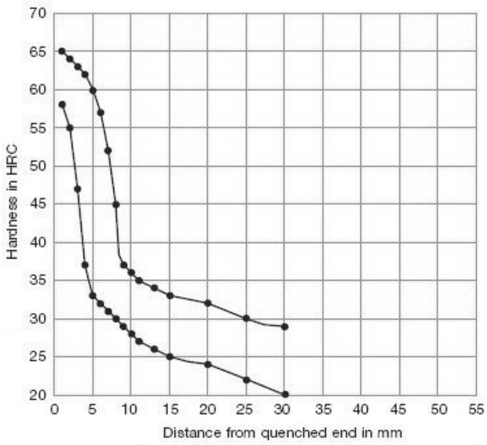

Fig. 2. Hardenability diagram C55E [5]

2.2. Characteristic of used welding technology

In order to minimize the degradation of material processed by the SPD technology, we chose the 141-GTAW welding technology in pulse mode, which enables precise thermal dosage and full control of the heat influence. The precise control of heat influence is necessary with respect to the need to maintain the maximal level of acquired properties after the SPD DRECE process. As a control joint, we chose an I joint without a root opening created on a single pass. The welding parameters of pulse welding are shown in Table 3.

Table 3.
Welding parameters for GTAW welding

Samples	I_1, A	I_2, A	U_1, V	U_2, V	t_1, s	t_2, s	v_w, cm/min
A-IS	40	13	9	8	0.7	0.1	11
B-6xDRECE	40	13	9	8	0.7	0.1	9

2.3. Evaluation of utility properties

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, measurement of micro-hardness, tensile test and measurement of residual stresses by the magnetoelastic method. Figure 3 shows test joints of given material in a default state and after being processed by the DRECE technology six times.

a)

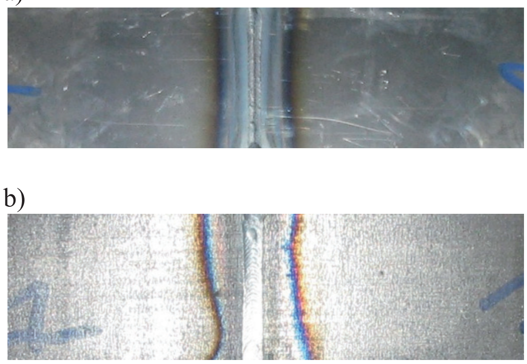

Fig. 3. GTAW weld sample-IS (a) and 6xDRECE (b)

a)

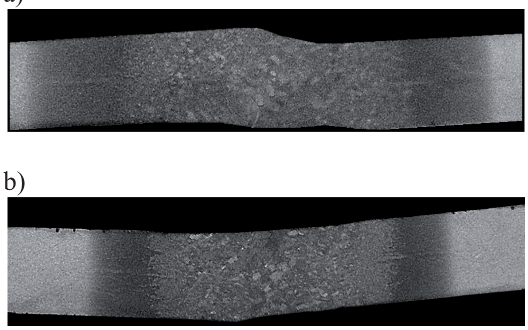

Fig. 4. Macrostructure GTAW weld sample-IS (a) and 6xDRECE (b)

Figure 4 shows the macro-structures of test joints. We did not detect any inadmissible defects such as ruptures, pores, or cold joints. The final deformation of joints had already been caused by the deformations of the initial semi-processed product after being processed by the DRECE technology. In case of sample A, the total HAZ width was 3.5 mm and the width of the coarse-grained region was 1.5 mm. In case of sample B, the HAZ width was 2.2 mm and the width of the coarse grained region was 1 mm. Figures 5-8 show the micro-structure of a joint from default state material and after being processed by DRECE six times. In the weld metal, we detected a martensitic structure; a mixture of martensite and tertiary cementite were found in the area of over-heating. in the default material not affected by heat, we detected speroidized pearlite, which subsequently moved into ferrite-pearlite structure in the HAZ.

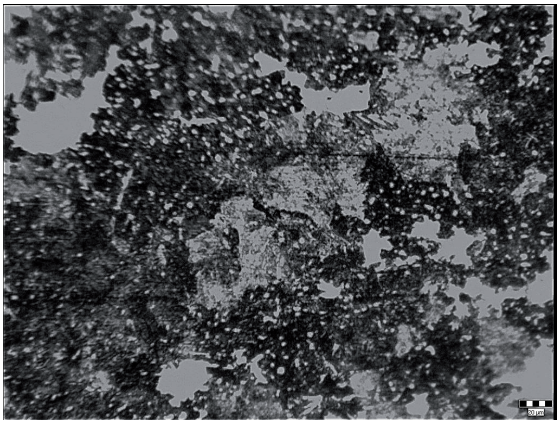

Fig. 5. HAZ microstructure A sample, Nital etched

Fig. 6. Weld metal microstructure A sample, Nital etched

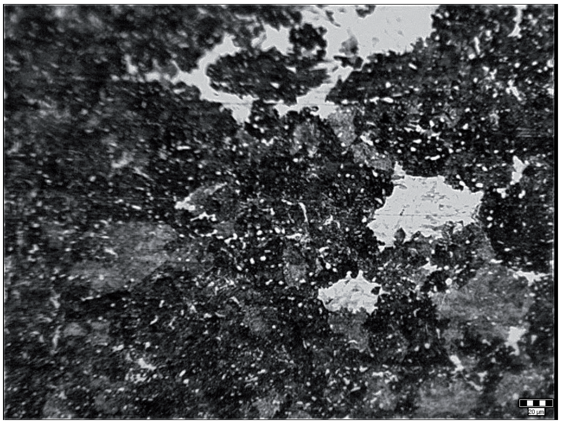

Fig. 7. HAZ microstructure B sample, Nital etched

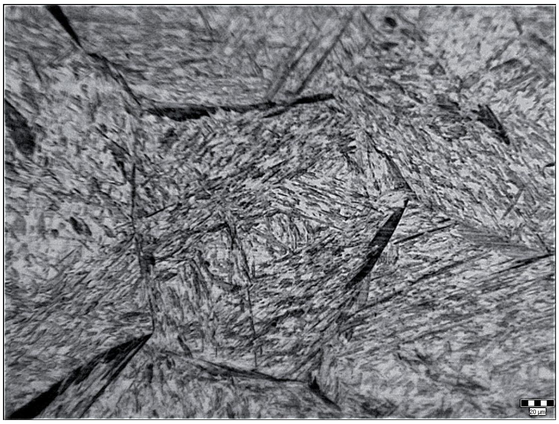

Fig. 8. Weld metal microstructure B sample, Nital etched

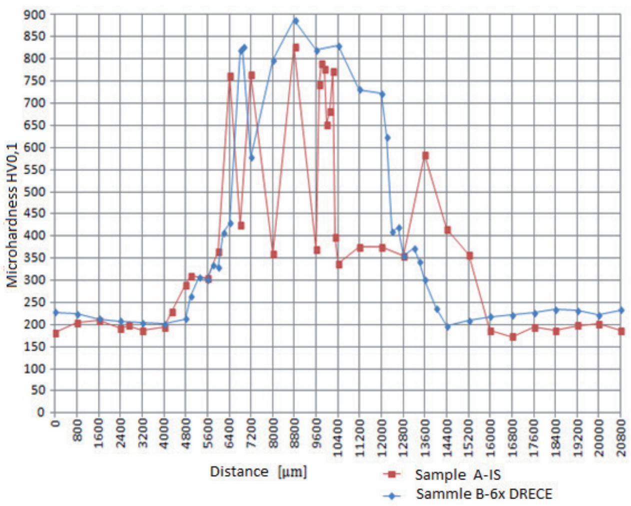

Fig. 9. Comparison of micro-hardness of welded joints A and B

Figure 9 shows the micro-hardness course according Vickers HV0.1 in direction perpendicular to the axis of weld for both samples. Toughness values in the default material move around 180 HV0.1. After DRECE process, the values rise to 225 HV0.1. In HAZ the maximal values move around 400 HV0.1, around 820 HV0.1 in the weld metal for sample A and around 867 HV0.1 for sample B as shown in Fig. 9. The rise in toughness in HAZ and weld metal is caused by the welding process and carbon diffusion.

We performed a measurement of residual stresses on the made joints using the magentoelastic method based on the methodology shown in [3,4,6-9]. The SPD DRECE technology brings significantly lower pressure stress into the material, which takes show positively on the weldability of a given material and reduces the formation of defects such as cold ruptures. Fig. 10 shows the course of residual stresses in the default material and in the weld joints of samples A and B. The achieved results show that an appropriately designed welding process does not degrade the properties acquired by the DRECE technology and compressive stress in the weld joint. We performed tensile test on sample B (weld joint GTAW + 6x DRECE) in two samples. We achieved average values R_m=550 MPa, $Rp_{0.2}$=455 MPa, A_5=2% on the joints. The area of breach was in the weld metal each time. In contrast to the values after the application of DRECE process without weld joint, the strength characteristics declined, which is necessary to take into account during construction designs.

3. Conclusion

Based on the experimental test performed, it is possible to draw the following conclusions. Using the DRECE technology leads to a significant rise of mechanical properties of a given carbon steel, and, in particular, bringing the residual pressure stresses into the materials. These premises then enable to consider successful fusible welding of a given difficultly weldable material. The impact of the welding technology on the resulting properties of weld joints from C55E steel after SPD DRECE process was verified by conducting mechanic and metallographic tests. The designed and verified method of welding (GTAW-pulse) with a precise regulation of the amount of thermal energy enables to achieve compact weld joints while maintaining all of the benefits acquired by using the DRECE technology. Even with a maximal effort, the utility functions do slightly decline while optimizing the welding technology. It is necessary to look for options of further minimizing the negative impact of welding in the application of concentrated sources of energy (PA, EB, LB), or alternatively, by using several thermal cycles of welding. Our future research will be focused in this direction.

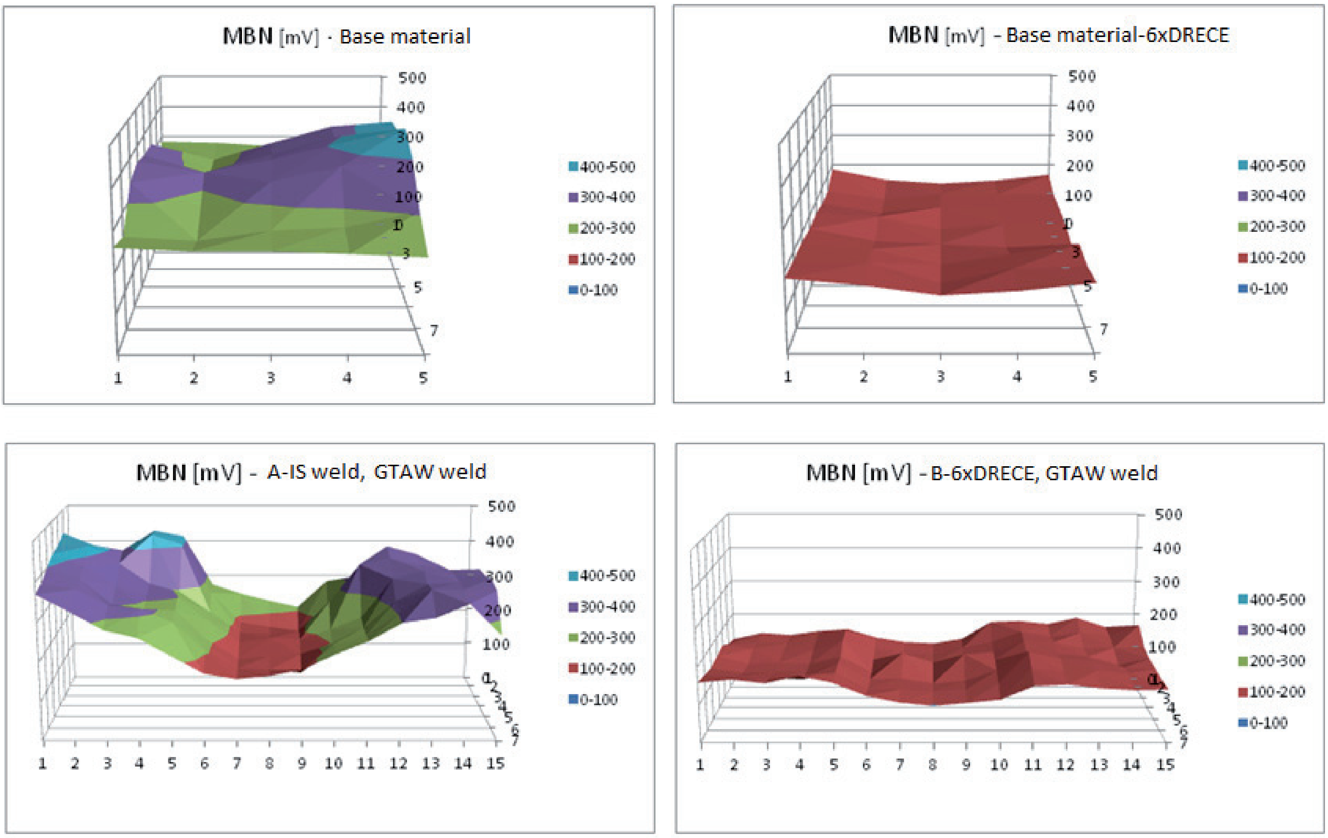

Fig. 10. Residual stresses analysis in the base metal and welded joints using MBN technique

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