INFLUENCE OF DRECE METHOD ON MECHANICAL PROPERTIES OF DIFFERENT LOW CARBON STEEL

[1]Pavel SZKANDERA, [1]Stanislav RUSZ, [2]Rostislav ZABYSTRZAN, [1]Jiří ŠVEC, [1]Ondřej HILŠER, [1]Martin PASTRŇÁK, [3]Radim KUROWSKI

[1]VSB - Technical University of Ostrava, Ostrava, Czech Republic, EU,
pavel.szkandera@vsb.cz, stanislav.rusz@vsb.cz, ondrej.hilser@vsb.cz, martin.pastrnak@vsb.cz

[2]STEELTEC CZ, s. r. o., Třinec, Czech Republic, EU, rostislav.zabystrzan@steeltec.cz

[3]KOVONA System a.s., Český Těšín, Czech Republic, EU, radim.kurowski@kovona-system.cz

https://doi.org/10.37904/metal.2021.4111

Abstract

Method DRECE (Dual Rolls Equal Channel Extrusion) belongs to a perspective group of technologies utilizing the process of severe plastic deformations (SPD). Used for forming of metallic materials. On the newly developed forming device, unlike the rolling technology, the material is significantly strengthening after the forming process, while maintaining the initial strip sheet dimensions after the first pass through forming device. We want to achieve a significant increase in mechanical properties in as few passages as possible by the forming device, in particular increasing the yield strength $R_{p0.2}$ and the ultimate tensile strength R_m, while maintaining good formability. The above-described forming method was used to extrude of two types low carbon steel HC200AM and S235JR. The forming tool, according to the pre-performed experiments, was chosen with an inclination of 108° in the deformation zone. The mechanical properties obtained after first pass through the forming device from the tensile tests.

Keywords: Severe plastic deformation process, DRECE method, HC200AM steel, S235JR steel, mechanical properties

1. INTRODUCTION

Ultra-fine-grained materials (UFG materials) were developed in a number of research projects. Research has found, that forming methods using severe plastic deformations process are very effective in the field of production of UFG materials. The SPD methods allow grain sizes of 100 to 200 nm to be achieved [1]. The resulting grain size can be affected by adjusting the forming parameters, for example by increasing the deformation pressure or by lowering the material temperature during forming [2]. The chemical composition of the formed material also has a significant effect on the resulting grain size [3]. The particle size of the grain mainly influences the degree of alloying of the formed material by interstitial atoms. Alloys formed by SPD methods achieve an increase in plasticity, strength or toughness. At UFG alloys also show effect superplasticity [4-6]. One of the new type of the severe plastic deformation method is called ECAP - Conform. This process usually consists of ECAP die and rotary pushing tool. The ECAP - Conform die consist of three important components. The rotating die, stationary die and the abutment. After insertion into the groove of the rotating die, the sample is pulled by the frictional force between the sample and the die until it hits the abutment. The ECAP- Conform tool is schematically shown in **Figure 1**. Another type of the severe plastic deformation method is called CECAP. The principle of the method consists in inserting a cylindrical sample into the inlet channel of the matrix. The deformation zone of the CECAP method consists of two parts. In the first part, the initial cylindrical metal is extruded to reduce its diameter (see **Figure 2**). The reduced sample reaches the end of the channel and is sufficient. Then the material is pressed into the angular channel to be laterally extruded.

The angular portion of the forming die provides the desired back pressure to compress the sample to increase its diameter to the initial state [8].

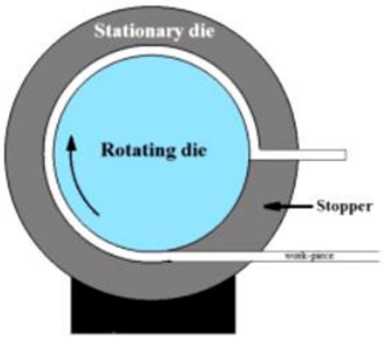


Figure 1 ECAP- Conform [7]

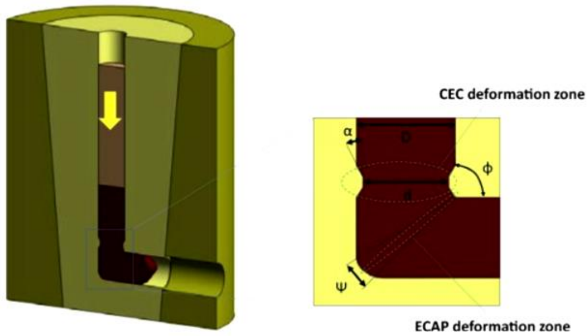


Figure 2 CECAP [8]

The paper verifies the mechanical properties of two types of low-carbon steels HC200AM and S235JR (used in the companies SteelTec.cz, s.r.o. and Kovona systém a.s.). The given steels will be formed by the DRECE (Dual Rolls Equal Channel Extrusion) method [9], which allows to achieve after the 1st pass through a special forming device a substantial increase in their mechanical properties, especially the yield strength R_e while maintaining the required plasticity. The DRECE method, unlike the rolling process, preserves the original dimensions of the sheet metal strip, ie. there is no change in the thickness of the formed sheet metal strip. The effect of method DRECE on increasing the basic mechanical properties, especially yield strength $R_{p0.2}$, ultimate tensile strength R_m, ductility A_{80}, determined by tensile test, was tested also from this perspective. The effectiveness of this method is evaluated by the use of different simulations [10]. The functionality of the forming device with a new DRECE method by the use of the SPD process has been verified, especially on non-ferrous metals and mild steels.

2. DRECE METHOD AND INNOVATIVE FORMING EQUIPMENT

Metallic strip with dimensions 58 x 2 x 1000 – 2000 mm (width x thickness x length) is inserted into the device. During the forming process the main cylinder in synergy with the pressure roller extrude the material through the forming tool without any change of cross section of the strip. In this way a significant refinement of grain is achieved by severe plastic deformation. This method is used for various types of metallic materials, non-ferrous metals and their alloys. The forming equipment is shown in **Figure 3**.

Figure 3 Forming equipment for DRECE method

Forming process is based on extrusion technology with zero reduction of thickness of the sheet metal with the ultimate aim - achieving a high degree of deformation in the formed material. Used DRECE method belongs to the group of a progressive type of forming processes making use of severe plastic deformation (SPD). After this processing step in comparison with structure of conventional materials, the materials exhibit significantly higher mechanical values, especially yield stress and in limited extent also tensile strength.

3. ANALYSIS OF SPD PROCESS INFLUENCE ON MECHANICAL PROPERTIES (CLASSIC TENSILE TESTS)

Experimentally was carried out 1 pass of steel HC200AM (see **Table 1**) through the forming device. After pass, the obtained mechanical properties were evaluated - see **Figure 4**.

Table 1 Chemical composition of HC200AM steel (in wt. %)

C (%)	Mn (%)	Si (%)	P (%)	S (%)
0.160	0.600	0.030	0.025	0.020

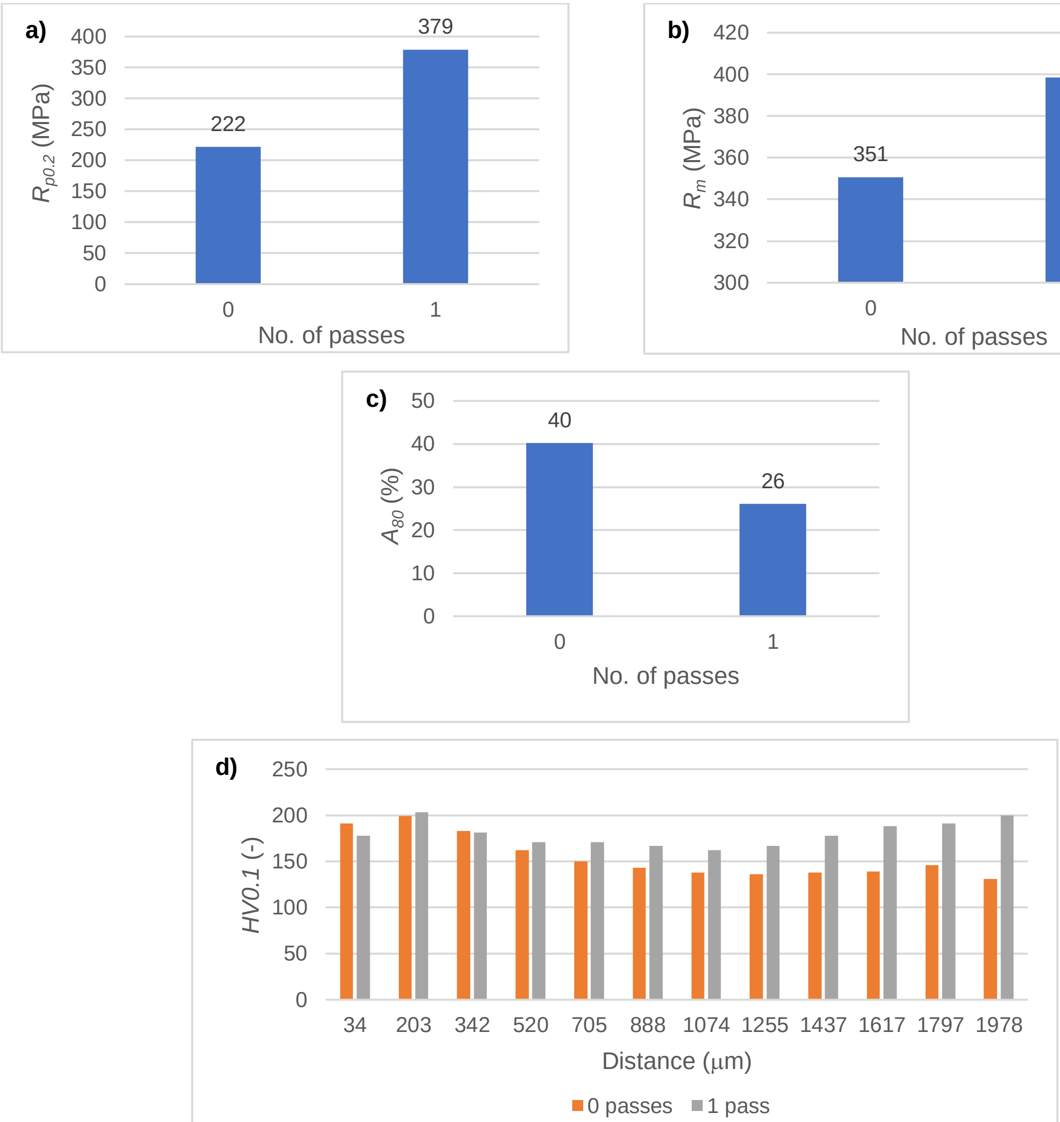


Figure 4 Influence of SPD process on a mechanical properties of steel HC200AM
a) Yield strength, b) Ultimate tensile strength, c) Ductility, d) Microhardness

On the basis of the results obtained from the tensile tests of steel HC200AM, it can be stated with respect to the initial state, that after the 1st pass the yield strength $R_{p0.2}$ is increased by 71 % and the ultimate tensile strength R_m by 14 % (see **Figure 4a** and **Figure 4b**). At the same time, there will be a slight decrease in the ductility by 14 % (see **Figure 4c**). As it is seen from the **Figure 4** the yield strength and ultimate tensile strength after SPD processing are increased while the elongation A_{80} is decreased. The ductility value A_{80} = 26 % is sufficient after the one pass through forming tool. The development of microhardness in the width of the sheet metal strip from the steel HC200AM is shown in **Figure 4d**.

Experimentally was carried out 1 pass of steel S235JR (see **Table 2**) through the forming device. After pass, the obtained mechanical properties were evaluated – see **Figure 5**.

Table 2 Chemical composition of S235JR steel (in wt. %)

C (%)	Mn (%)	P (%)	S (%)	N (%)	Cu (%)
0.170	1.400	0.035	0.035	0.012	0.550

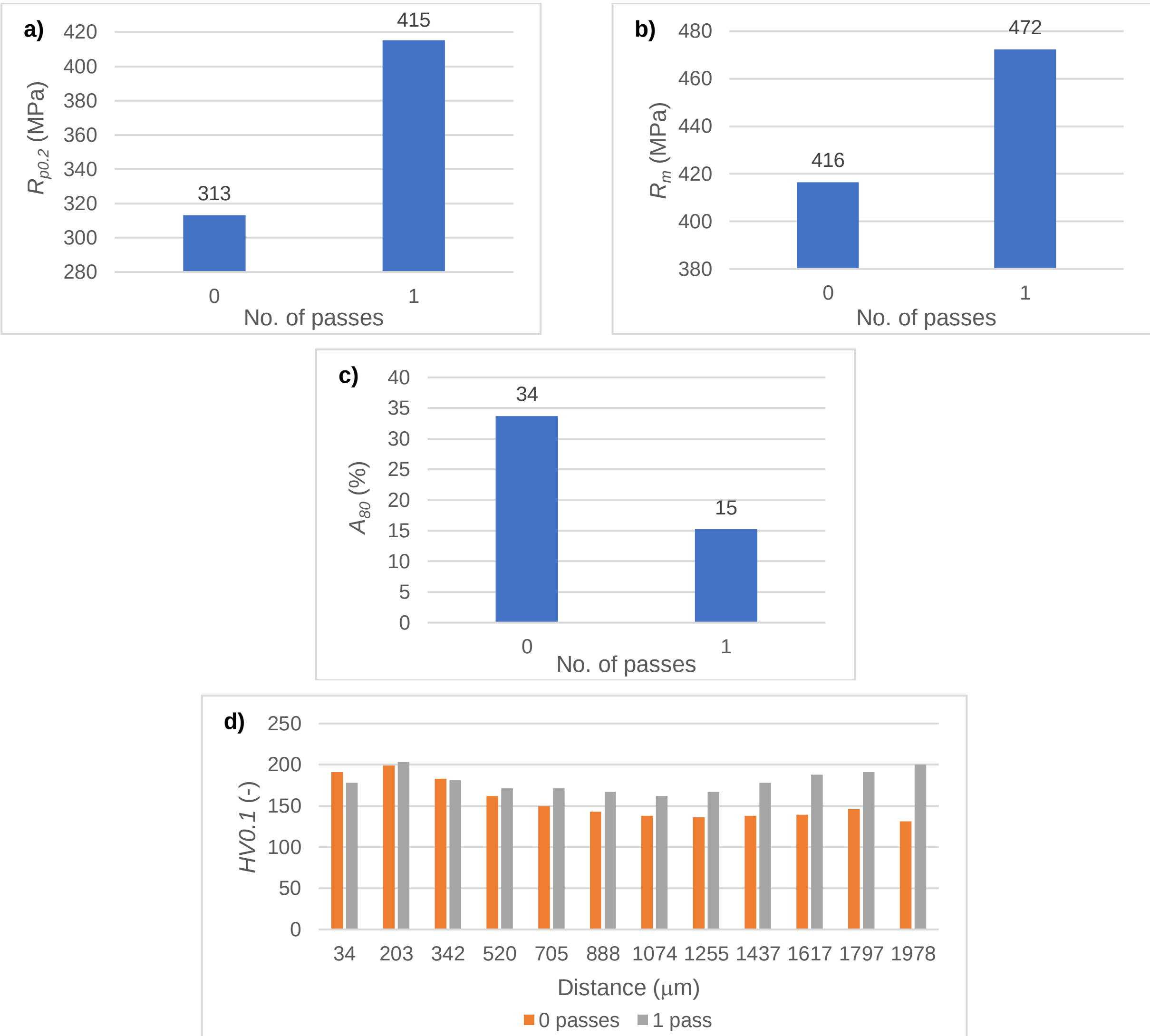


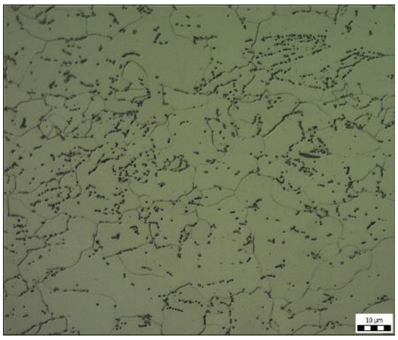
Figure 5 Influence of SPD process on a mechanical properties of steel S235JR
a) Yield strength, b) Ultimate tensile strength, c) Ductility, d) Microhardness

On the basis of the results obtained from the tensile tests of steel S235JR, it can be stated with respect to the initial state, that after the 1st pass the yield strength $R_{p0.2}$ is increased by 33 % and the ultimate tensile strength R_m by 13 % (see **Figure 5a** and **Figure 5b**). At the same time, there will be a slight decrease in the ductility by 19 %. As it is seen from the **Figure 5** the yield strength and ultimate tensile strength after SPD processing are increased while the elongation A_{80} is decreased. The ductility value A_{80} = 15 % is sufficient after the one pass through forming tool. The development of microhardness in the width of the sheet metal strip from the steel S235JR is shown in **Figure 5d**.

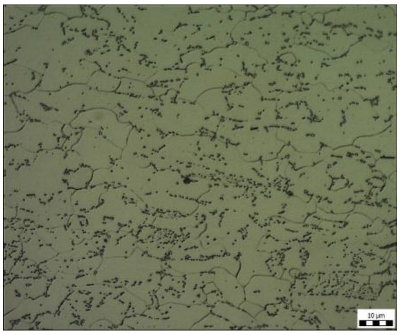
From the achieved results of the mechanical properties in the short tensile, it is obvious that according to the results achieved by the classic tests, the highest reinforcement in the sheet metal after the 1st pass through the forming tool occurs both in longitudinal, transverse and deflected directions. After the 1st pass, there is a large build-up of dislocations at the grain boundaries and thus to the intensive strengthening of the steel. At the same time, the ductility is reduced considerably. An important knowledge of industrial practice is the size of the steel strengthening after the first passes by the forming device, the achieved ductility value being sufficient for the further forming of the sheet.

4. MICROSTRUCTURE ANALYSIS

The microstructure analysis of steels HC200AM and S235JR showed a less pronounced effect of the SPD process on grain refinement. After the 1th pass through the forming tool, there is only very slight refinement of the structure (see **Figure 6** and **Figure 7**). In the further course of the research, it seems appropriate to carry out a suitable heat treatment (structure refinement) on the 1th pass in order to reduce the increase in mechanical properties as the elongation value increases.

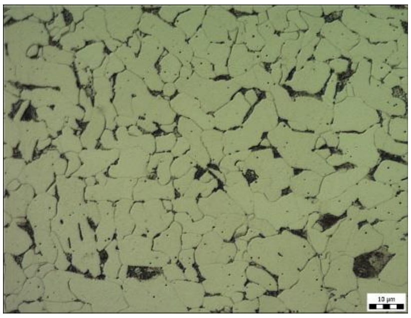


a) initial state

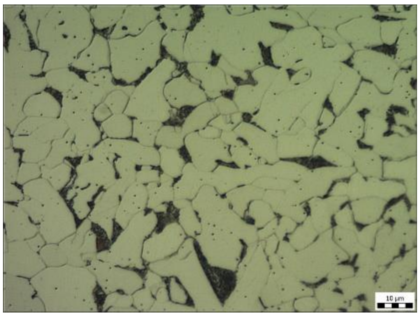


b) after 1th pass (longitudinal direction)

Figure 6 Microstructure of the steel HC200AM



a) initial state



b) after 1th pass (longitudinal direction)

Figure 7 Microstructure of the steel S235JR

5. CONCLUSION

From the results of this experiment, the effect of the SPD process on the quality improvement of the HC200AM and S235JR steels is obvious. In particular, it is an increase of the yield strength while maintaining the desired formability after the 1st pass by the forming device. At the same time, there is a considerable reduction of the formability (ductility). A dislocation-reinforced structure was achieved. In terms of grain refinement, which is important to maintain the required ductility, it will be desirable to carry out a suitable inter-operative heat treatment. For the application of prototype equipment in industrial practice, the mechanical properties of the HC200AM and S235JR steels are very important. After the 1st pass through the forming device, the yield strength $R_{p0.2}$ is substantially increased, while maintaining the necessary ductility A_{80} required to further deformation of the sheet metal. The suitability of using the DRECE method to improve the quality of these steels on prototype forming equipment has been clearly demonstrated.

ACKNOWLEDGEMENTS

This paper was created within the projects Production technology of a sheet strip with an ultra- fine grain structure, No. CZ.1.05/3.1.00/14.0320, project Epsilon Technology Agency of the Czech Republic, Development of a new technology for increasing the quality of steel strips, No. TH04010416 and project Innovative and additive manufacturing technology - new technological solutions for 3D printing of metals and composite materials, reg. no. CZ.02.1.01/0.0/0.0/17_049/0008407 financed by Structural and Investment Founds of Europe Union.

REFERENCES

[1] TOTH, L.S., GU, CH. Ultrafine-grained metals by severe plastic deformation. *Materials Characterization.* 2014, vol. 92, pp. 1-14.

[2] VALIEV, R.Z., ISLAMGALIEV, R.K., ALEXANDROV I.V. Bulk nanostructured materials from severe plastic deformation. P*rogress in Materials Science*. 2000, vol. 42, pp.103-189.

[3] ZRNÍK, J., DOBATKIN, S.V., MAMUZIČ, I. Processing of metals by severe plastic deformation (SPD)-structure and mechanical properties respond. *Metalurgija.* 2008, vol. 47, no. 3, pp. 211-216.

[4] RAAB, A.G., CHUKIN, M.V., ALESHIN, G.N. RAAB, G.I. Investigation of a new shear deformation method for the production of nanostructures in low-carbon steel. In: *IOP Conference Series: Materials Science and Engineering 63.* France, 2014, pp. 1-5.

[5] AZUSHIMA, A., KOPP, R., KORHONEN, A., YANG, D.Y., MICARI, F., LAHOTI, G.D., GROCHE, P., YANAGIMOTO, J., TSUJI, N., ROSOCHOWSKI, A., YANAGIDA, A. Severe Plastic Deformation (SPD) Processes for Metals. *Manufacturing Technology*. 2008, vol. 57, no. 2, pp. 716-735.

[6] SNOPIŃSKI, P., TAŃSKI, T. Effect of heat treatment combined with high pressure torsion process on microstructure and hardness of AlMg5Si2Mn alloy. *Solid State Phenomena*. 2018, vol. 275, pp. 89-99.

[7] DERAKHSHAN, J., FAKHIMI, J., PARSA, M.H.A., JAFARIAN, H.R. Microstructure and mechanical properties variations of pure aluminum subjected to one pass of ECAP-Conform process. *Materials Science and Engineering*: *A*. 2019, vol. 747, pp. 120-129.

[8] ENSAFI, M., GHADER, F., HOOMA, A. Cyclic extrusion compression angular pressing (CECAP) as a novel severe plastic deformation method for producing bulk ultrafine grained metals. *Materials Letters*. 2017, vol. 197, pp. 12-16.

[9] RUSZ, S., HILŠER, O., OCHODEK, V., ČADA, R., ŠVEC, J., SZKANDERA, P. Influence of SPD on low-carbon steel mechanical properties. *MM Science Journal*. 2019, pp. 2910-2914.

[10] VINOGRADOV, A., ESTRIN, Y. Extreme grain refinement by severe plastic deformation: A wealth of challenging science. *Acta Materialia*. 2013, vol. 61, no. 3, pp. 782-817.