INFLUENCE OF SPD PROCESS ON MECHANICAL PROPERTIES IN LOW CARBON STEEL

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Abstract

Development of technologies for the production of the very fine structure is currently very intensively accelerated. Even in scientific research, it is recognized that precisely controlled forming processes, including special processes, enabling control of technological parameters with regard to the structure refinement, and tied with the strengthening of materials, currently had the highest gradient of utilization efficiency of the scientific research findings in practice. New forming equipment using the process SPD is currently installed in the laboratory for the development of new technologies at the Faculty of Mechanical Engineering - VSB-TU Ostrava. The paper analyses the effects of the values of angles of the newly developed forming tools on the achievement of mechanical properties in selected low carbon steels in the SPD process. The following types of steels were verified experimentally: DC01 and S355 - strip sheet with dimensions 58 (width) x 2 (thickness) x 1000 (length) mm. The paper also evaluates the influence of severe plastic deformation (SPD) on strengthening these steels at different values of the angle in the forming tool. The influence of new geometries of forming tools for improving mechanical properties has been unequivocally demonstrated.

Keywords: Severe plastic deformation, low carbon steels, mechanical properties, forming tools

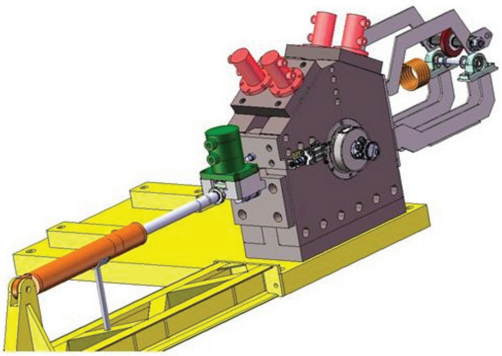
1. INTRODUCTION

Development of technologies for the production of very fine-grained materials is currently very intensively accelerated. Even in scientific research, it is recognized that namely the controlled forming processes, including special processes, enabling control of technological parameters with regard to the structure and its further refinement, have currently the highest gradient of utilization efficiency of scientific research findings in practice. Regarding these drawbacks, a new deformation approach is developed for the continuous production of sheet or strip products with UFG microstructure, called equal channel angular rolling method (ECAR); developed by Lee et al. by modifying the ECAP process [1, 2]. Since the ECAR method is a continuous process, it is more worthy of attention than other SPD techniques and conventional cold rolling processes. The studies on Mg alloy [3, 4, 8] have shown that SPD via ECAR process causes a reduction in strength and an increase in elongation. Also, the formability was increased due to change from the basal plane to the non-basal plane of crystal orientation and propagation of twins after ECAR. This behavior of specimens of Mg alloys processed by ECAR is in contrast with the response of other metals, such as Cu [5, 6,] and steel [7]. In the metals like Cu and steel, the deformation by ECAR increases the strength and decreases elongation. Besides the DCAP (C2S2) and ARB method for sheet metal forming, from the perspective of industrial practice new technologies are being intensively developed, to which belongs also the newly developed DRECE method (Dual Rolls Equal Channel Extrusion, see **Figure 1a)**, which were improved by the use of new forming tools with a new geometry (smaller angles in the zone of deformation, see **Figure 1b)**. The issues of production of materials with UFG structure, especially in steels and alloys of non-ferrous metals in the form of sheet metal strip are analyzed in detail. Furthermore, a comparison is made of basic mechanical properties of the tested materials achieved after severe plastic deformation with the properties of these materials in the initial state. Analysis of the structure is performed on an optical microscope. The ECAR method is one of the similar methods of forming, approaching a continuous production process.

Unlike the DRECE method it works with totally different inputs and also with hot forming, although it has a lower strengthening, but it lacks a dislocation strengthening as a source of grain refinement. From this perspective, this newly developed method of forming (DRECE) is completely original.

2. PROPRIETARY FORMING EQUIPMENT

The equipment (**Figure 1**) consists of the following main parts: transmission of the type Nord with electric drive, multi-disk clutch, feed roller and pressure rollers with variable regulated thrust force, the forming tool as such made of the Dievar type steel. The strip sheet had dimensions 58 x 2 x 2000 mm. Structural modifications of the equipment made it possible to push at present the metal strip with the lengths up to 2000 mm. The metal strip is inserted into the working space and it is pushed by the feed roller in interaction with pressure rollers through the forming tool without any change of the cross-section.



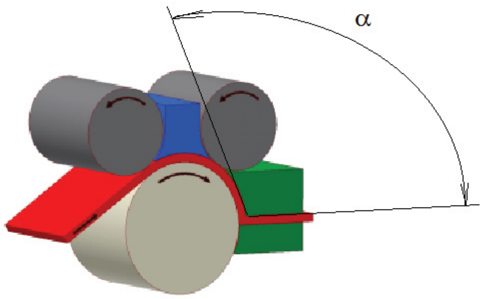


Figure 1 left Diagram of innovated forming equipment (DRECE method), **right** Scheme of deformation zone with different angle α

2.1. Specification of conditions of the presented experiments

At thus performed severe plastic deformation it is possible to achieve a substantial enhancement of mechanical properties while maintaining the necessary plasticity. The geometry of forming tools, in particular, the inclination angle of the approach of the forming curve in the zone deformation, is a very important factor influencing the efficiency of the SPD process. This is currently newly developed forming equipment with 6 protected industrial designs of new geometries of the forming tools. Two types of low carbon steels suitable for cold forming were verified experimentally. It was namely deep-drawing steel DC01 and comparative steel S355. The tests were performed on the upgraded forming equipment using the principle of cold severe plastic deformation (method DRECE - dual pressure combined with the extrusion channel of the constant cross-section). Apart from materials, particularly the geometry of the forming tools is a very important factor of the forming method DRECE. The effect of various angles of the forming tools fro on influencing the basic mechanical properties, especially yield stress $R_{p0.2}$, tensile strength R_m and ductility A_{80}, determined by tensile test, was tested also from this perspective. It is known from the available literature data [2, 8] that namely these angles determine the zone of plastic deformation.

3. RESULTS ACHIEVED IN SELECTED STEELS

The chemical composition of the two steels is given in **Table 1.**

Table 1 Chemical composition of tested steels DC01 and S355

Steel	C	Mn	Si	P	S	Ni	Cr	Mo	V	Nb	Ti	Al
DC01	0.029	0.211	0.009	0.008	0.013							0.059
S355	0.104	0.549	0.025	0.021	0.005	0.012	0.034	0.011	0.002	0.028	0.001	0.012

3.1. Tests performed with the use of the tool with an angle of 108°

The **Table 2** contains the results of tensile tests both in the initial state (VS) and after the individual passes through the forming equipment for DC01. The obtained results are clearly graphically presented in the following **Figure 2**.

Table 2 Basic mechanical properties of the steel DC01

	Yield stress $R_{p0.2}$ (MPa)	Tensile strength R_m (MPa)	Ductility A (%)
Initial State	194	302	52.7
1st pass	319	353	18.7
2nd pass	332	375	15.3
3rd pass	349	392	18

The results of tensile tests both in the initial state (VS) and after the individual passes through the forming equipment for DC01 is given in the **Table 3**. The obtained results are clearly graphically presented in the following **Figure 2**

Table 3 Basic mechanical properties of the steel S355

	Yield stress $R_{p0.2}$ (MPa)	Tensile strength R_m (MPa)	Ductility A (%)
Initial State	345	466	36
1st pass	409	487	18.7
2nd pass	418	496	17.3
3rd pass	431	509	17.3

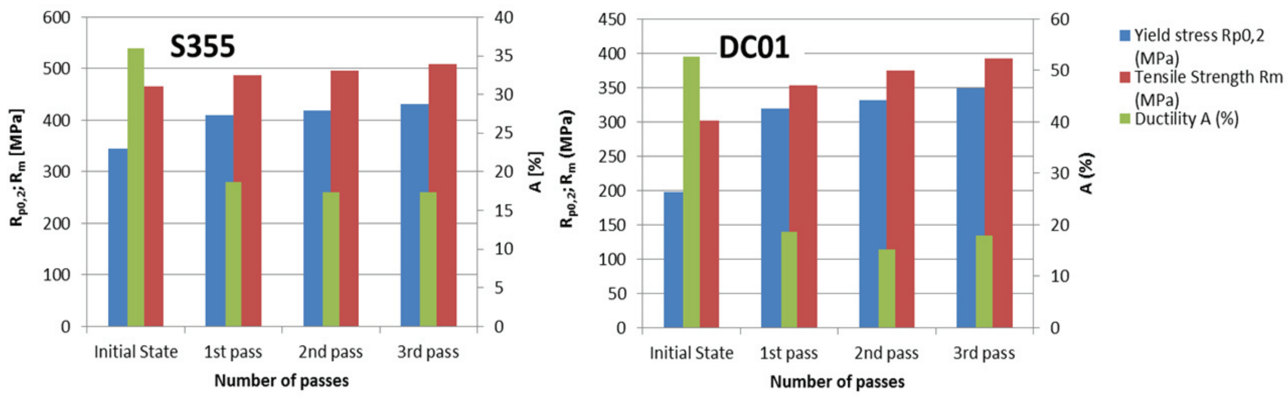


Figure 2 Comparison of basic mechanical properties of the initial material of the steels DC01and S355 after individual passes through the forming equipment

With the use of the angle of the forming tool of 108° the effect of this angle on mechanical properties in individual passes was verified for the steels DC01 and S355. It was demonstrated that in both these steels a significant increase of the yield stress $R_{p0.2}$ occurs already after the first pass through the forming tool. This finding is very important for industrial practice, where after possible implementation of the forming equipment into the production line it is not necessary to incorporate another - second equipment (for the 2nd pass).It is thus possible to achieve a substantial reduction of the costs for implementation of this new forming method into industrial practice.

4. INFLUENCE OF THE CHANGE OF THE VALUES OF ANGLES OF THE FORMING TOOLS ON THE ACHIEVED MECHANICAL PROPERTIES.

In the next phase of verification of the effects of geometry of the forming tools, we conducted also testing of bigger angles of 113° and 118°. A general overview of the mechanical properties achieved by application of the tools with those angles is presented in **Tables 4 and 5** for the steel DC01 and in **Tables 6 and 7** for the comparative high-strength steel S355. This comparison is made both for initial states (IS) and for the states of materials after individual passes through the forming tool for 4 realized test passes.

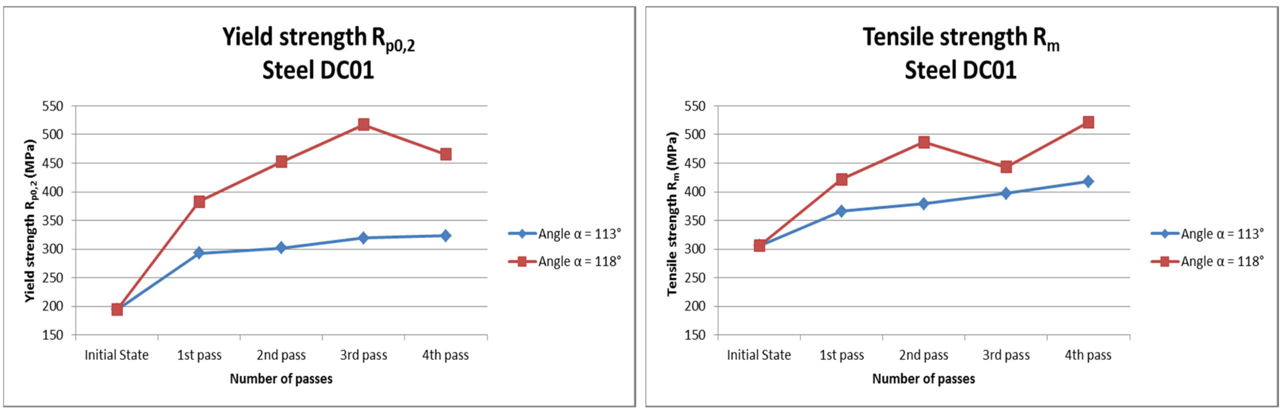
Table 4 Steel DC01, Angle α = 113°

	Yield stress $R_{p0.2}$ (MPa)	**Tensile strength R_m (MPa)**	**Ductility *A* (%)**
Initial State	194	306	43.3
1st pass	293	366	17.3
2nd pass	302	379	16.7
3rd pass	319	397	9.3
4th pass	323	418	8.7

Table 5 Steel DC01, Angle α = 118°

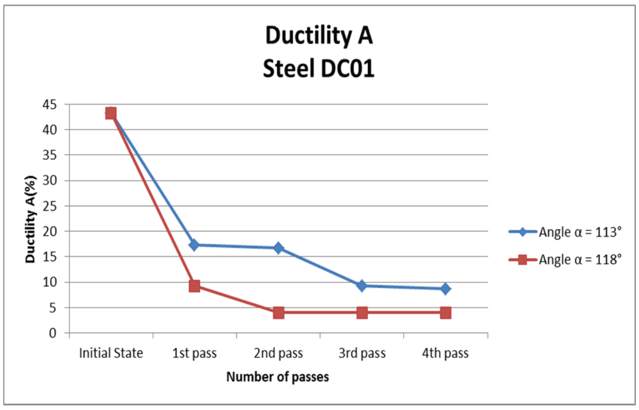
	Yield stress $R_{p0.2}$ (MPa)	**Tensile strength R_m (MPa)**	**Ductility *A* (%)**
Initial State	194	306	43.3
1st pass	383	422	9.3
2nd pass	452	487	4.0
3rd pass	517	443	4.0
4th pass	465	522	4.0

Graphical comparison of the effects of both types of investigated instruments on the changes of the mechanical properties, both strength and plastic, are shown in **Figure 3a - c** for the steel DC01 and then also in **Figure 4a - c** for the high-strength low carbon steel of the type S355.



a) b)

Figure 3 Comparison of the $R_{p0.2}$ (a) ; R_m (b) and *A* (c) of the initial material of the steel DC01 and after individual passes through the forming equipment



c)

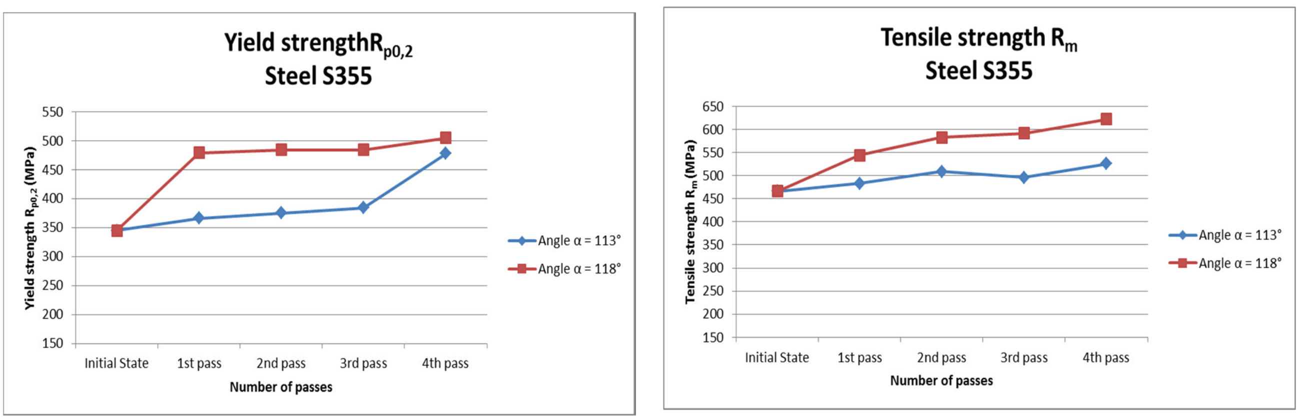
Figure 3 Comparison of the $R_{p0.2}$ (a) ; R_m (b) and A (c) of the initial material of the steel DC01 and after individual passes through the forming equipment (continuation)

Table 6 Steel S355, Angle α = 113°

	Yield stress $R_{p0.2}$ (MPa)	Tensile strength R_m (MPa)	Ductility A (%)
Initial State	345	466	36.0
1st pass	366	483	22.7
2nd pass	375	509	14.7
3rd pass	384	496	12.0
4th pass	478	526	10.0

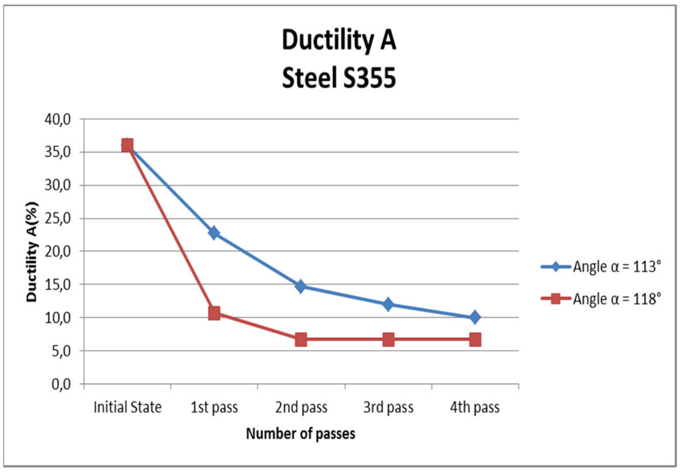
Table 7 Steel S355, Angle α = 118°

	Yield stress $R_{p0.2}$ (MPa)	Tensile strength R_m (MPa)	Ductility A (%)
Initial State	345	466	36.0
1st pass	479	544	10.7
2nd pass	484	583	6.7
3rd pass	484	592	6.7
4th pass	505	622	6.7



a) b)

Figure 4 Comparison of the $R_{p0.2}$ (a) ; R_m (b) and A (c) of the initial material of the steel S355 and after individual passes through the forming equipment



c)

Figure 4 Comparison of the $R_{p0.2}$ (a) ; R_m (b) and *A* (c) of the initial material of the steel S355 and after individual passes through the forming equipment (continuation)

Initial states in all presented figures and tables were naturally not been influenced by the forming process. They are, however, shown in tables and graphs for clarity of the comparison of determined effects of the severe plastic deformation.

5. CONCLUSIONS

All realized experiments demonstrated a significant effect of the newly developed forming tools with the abovementioned angles on the increase of the strength properties after various passes in both tested materials.

With the use of the forming tool with an angle of 118° higher values of the yield stress $R_{p0.2}$ and of the tensile strength R_m were achieved than with the use of the forming tool with an angle of 113°. This phenomenon is attributed to the influence of the tool geometry on the stress-strain state in the zone of deformation, which then acts on strengthening mechanisms in the structure of the examined materials. The achieved results demonstrated the suitability of the angle of 118° for both types of the examined steel.

At present, other types of materials are verified, which have pre-requisites for achieving an enhancement of the strength mechanical properties with still acceptable reduction of plastic properties (ductility).

It was demonstrated that in both investigated steels a significant increase in the yield stress $R_{p0.2}$ was achieved already after the first pass through the forming tool. The first results of the verification of the effects of the tool geometry and of other parameters influencing the state of stress in the deformation zone indicate a direction for further exploration of the DRECE method in the laboratories of the Department of Mechanical Technology of the Faculty of Mechanical Engineering at the VSB - Technical University of Ostrava.

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