STUDY OF MECHANICAL PROPERTIES OF STEEL AND SELECTED TYPES OF NON - FERROUS ALLOYS AFTER APPLICATION OF THE DRECE PROCESS

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Abstract:

The article describes the influence of an unconventional forming method, such as DRECE, on the resulting mechanical properties and structure of tested materials. In the laboratories of the Technical university of Ostrava we have prototype equipment DRECE for production of very fine grained or nanostructured materials in the form of metal strips. The research is focused on perspective materials, mainly on non – alloyed steels and on selected types of non – ferrous alloys. Material after application of the DRECE process has diametrically increased mechanical properties (Ultimate strength, Yield strength, Hardness, etc.). Ultra - fine - grained (UFG) or nanostructured materials represent a new generation of advanced materials exhibiting unique and technologically attractive properties due to dimension and relationship outcomes. Possibilities of nanostructured materials to change many technologies are almost unprecedented.

Keywords: **DRECE method, Steel DC01, EN AW 3003, EN CW 508L, Tensile test, Structure**

1. INTRODUCTION

Nanostructured materials are defined as solids having microstructural features in the range of 1 - 100 nm in at least one dimension [1].

The grain size of polycrystalline materials plays a major role in dictating many critical properties including the strength and resistance to plastic flow. In general, materials with small grain sizes have several advantages over their coarse-grained counterparts because they have higher strength and other favorable properties including a potential for use in superplastic forming operations at elevated temperatures. This significance was recognized several years ago and led to the concept of nanocrystalline materials which were discussed in detail in an early review [2].

A possible avenue for microstructure refinement of metals is the use it is appropriate to mention that many of the modern ideas of severe plastic deformation (SPD - a principle that is of thermomechanical processing involved in virtually all as old as metalworking itself [3]. It is important to note that the shape of the sample is retained in SPD processing by the use of special tool geometries which effectively pre- vent free flow of the material and thereby produce a significant hydrostatic pressure which leads to a high density of lattice dislocations and consequent grain refinement [2].

2. THE DRECE PROCESS

Large plastic deformation is an efficient tool for reducing the grain size of metals down to the ultrafine - grain regime or even to nanosizes in alloys. A large number of severe plastic deformation (SPD) processes have already been proposed for grain refinement, some of which are continuous processes. One continuous SPD process is equal - channel angular pressing and Conform (ECAP - Conform), in which a sheet is pressed through a die with the help of rotating wheels. It is expected that continuous SPD processes will be introduced into industrial production, thus it is important to study the transformation of material properties in such processes [4].

Our department presently features of DRECE machinery for forming metal plates with dimensions of 58 × 2 × 1000 mm. It is also possible to use a smaller thickness of sheets, by adapting the pitch deformation zone using distance washer placed under the pressure rollers. We further studied the effect of the passes by DRECE tool on the final microstructure and mechanical properties of these materials [5].

The entire DRECE equipment is shown in Fig. 1.

Fig. 1 The DRECE equipment

3. EXPERIMENTAL MATERIALS

We tested effect of the DRECE process (ferrous and non – ferrous materials) on the final properties, see Chapter 2.

3.1 Steel DC 01

Thin sheet metal made from non - alloyed steel of enhanced quality and cold - rolled according to ČSN EN 10131. The sheet metal is suitable for medium drawing, cold - forming, varnishing, deep - drawing. Rimmed steel has a tendency to age after cold - rolling. Chemical composition of the steel DC 01 is presented in Table 1.

Table 1 Chemical composition of the steel DC 01

Element	C	Mn	Al	P	S
% by mass	0,10	0,43	0,02	0,03	0,03

3.2 Aluminium alloy EN AW 3003

Typical chemical composition of this type of Al alloy is presented in Table 2.

Table 2 Chemical composition of the aluminium alloy EN AW 3003

Element	Si	Fe	Cu	Mn	Zn	Al
% by mass	0,60	0,70	0,20	1,50	0,10	rest.

3.3 Brass EN CW 508L

Chemical composition of the brass is presented in Tables 3.

Table 3 Chemical composition of the brass EN CW 508L

Element	Sn	Al	Zn	Mn	Si	Fe	Cu
% by mass	0,43	0,15	34,2	0,45	0,10	0,06	rest.

4. MECHANICAL PROPERTIES

Mechanical properties were obtained in cooperation with the VÚHŽ Dobrá a.s. research institute. These are presented mainly for better evaluation of the actual technological tests. Mechanical properties of studied samples were tested by Vickers hardness method on the HPO 250 testing device and tensile test on the Inova TSM 50 testing machine was realized.

Summaries the results of the mechanical properties of low carbon steel, aluminium alloy and brass are presented in Tables 4 – 6.

Table 4 Mechanical properties of the steel DC01

Mechanical properties of the steel DC 01				
	$Rp_{0,2}$ [MPa]	R_m [MPa]	A_{80} [%]	HV10 [-]
Initial state	173	311	50	93
DRECE 2×180°	370	391	22	122
DRECE 4×180°	382	411	16	135
DRECE 6×180°	390	415	15	136

Table 5 Mechanical properties of the aluminium alloy EN AW 3003

Mechanical properties of the aluminium alloy EN AW 3003				
	$Rp_{0,2}$ [MPa]	R_m [MPa]	A_{80} [%]	HV5 [-]
Initial state	115	131	22	41
DRECE 2×180°	135	163	10	52
DRECE 4×180°	152	173	14	60
DRECE 6×180°	152	171	13	61

Table 6 Mechanical properties of the brass EN CW 508L

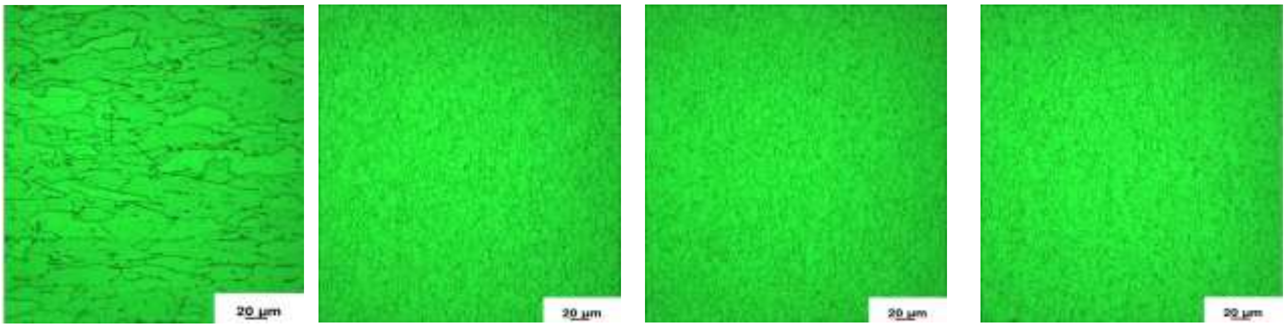
Mechanical properties of the brass EN CW 508L				
	$Rp_{0,2}$ [MPa]	R_m [MPa]	A_{80} [%]	HV5 [-]
Initial state	238	350	48	93
DRECE 2×180°	305	392	44	127
DRECE 4×180°	375	450	14	150
DRECE 6×180°	361	438	14	160

Average values of hardness from five measurements were calculated. As it can be seen from these tables the values rapidly increase from the 1st to 4th passes. After the 4th pass the value of hardness stays nearly the same.

It may be assumed from this dependence, that the biggest increase of mechanical properties caused by dislocation strengthening in the course of plastic deformation occurs till the 4th pass and subsequent passes do not contribute substantially to further increase of strengthening.

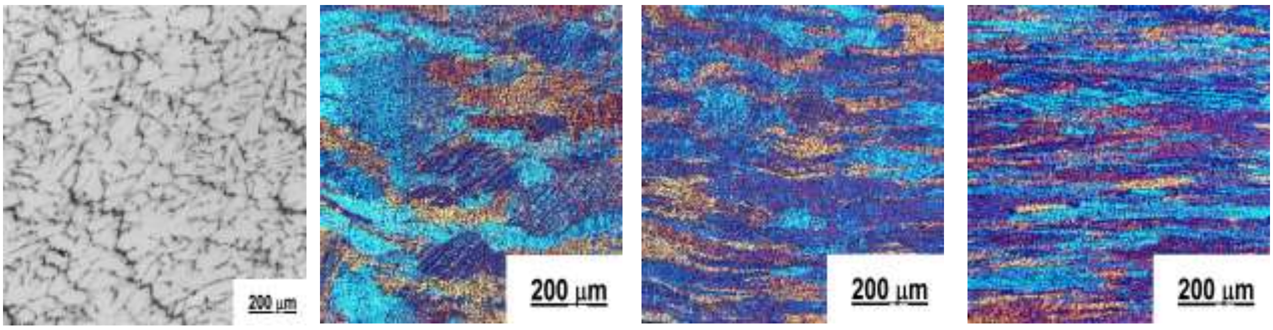
5. METALLOGRAPHIC ANALYSIS

Metallographic analysis was made on light microscope NEOPHOT 2. After usual metallographic preparation the samples were chemically etched.



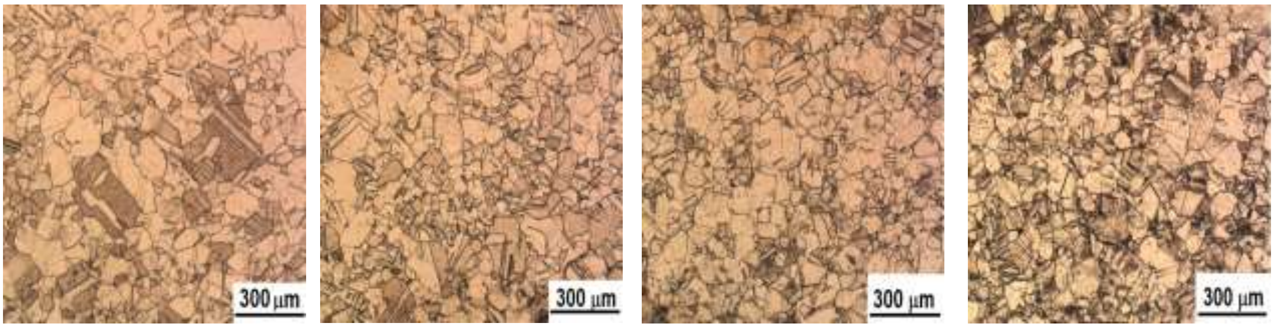
a) **b)** **c)** **d)**

Fig. 2 Structure of the steel DC 01, a) initial state, b) after 2nd pass, c) after 4th pass, d) after 6th pass



a) **b)** **c)** **d)**

Fig. 3 Structure of the EN AW 3003 alloy, a) initial state, b) after 2nd pass, c) after 4th pass, d) after 6th pass



a) **b)** **c)** **d)**

Fig. 4 Structure of the brass EN CW 508L, a) initial state, b) after 2nd pass, c) after 4th pass, d) after 6th pass

Figures 2 – 4 shows microstructures of the tested materials.

Micro-structure of investigated steel in initial state is formed by slightly elongated ferrite grains and by fine perlite particles. As it is evident from the above photos of micro - structures of the verified low - carbon steel DC01 small refining of structure occurred during the DRECE process (Fig.2).

Fig. 3 shows micro - structure of samples of the brass. This microstructure consists of grains in agreement with the fact that this material was formed before the DRECE processing.

Microstructures of EN AW 3003 alloy samples are shown in Fig. 4. As it can be seen from these micrographs, refining of grains after each pass was only small. From the reason deformation of materials we can presume creation of sub - grains which will be studied with application EBSD method.

6. CONCLUSION

The obtained results of experimental verification of structure refining by DRECE process have confirmed suitability of this technology for production of UFG structure in low - carbon steel, which leads to substantial increase of mechanical properties. Substantial increase of yield strength $Rp_{0,2}$, ultimate strength R_m and hardness HV10 (HV5) was achieved, which opens up much broader possibilities of its use for manufacture of high strength machine components (value of the given steel grade is increased).

The equipment DRECE is at the stage of verification and future works will verify influence of technological parameters on the increase of efficiency of SPD process for obtaining the UFG (NC) structure in steels and non - ferrous metals, but for verifying of technology influence on the final formed materials structure must be tested on an electron microscope (TEM, EBSD methods).

The important thing is maintaining a reasonable degree limit of plasticity (elongation) of the material after application of the DRECE process. It may be assumed from dependence mechanical properties on number of passes, that the biggest increase of hardness caused by dislocation strengthening in the course of plastic deformation occurs till the 4th pass and subsequent passes do not contribute substantially to further increase of strengthening.

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REFERENCES

[1] ZHU Y. T., LOWE T. C., LANGDON T. G. Performance and applications of nanostructured materials produced by severe plastic deformation. Scripta Materialia, Vol. 51, Issue 8, 2004, pp. 825 – 830.

[2] ZHILYAEV A. P., LANGDON T. G. Using high – pressure torsion for metal processing: Fundamentals and applications. Progress in Material Science, Vol. 53, Issue 6, 2008, pp. 893 – 979.

[3] VINOGRADOV A., ESTRIN Y. Extreme grain refinement by severe plastic deformation: A wealth of challenging science. Acta Materialia, Vol. 61, Issue 3, 2013, pp. 782 – 817.

[4] GU C. F., TOTH L. S., RUSZ S., BOVA M. Texture induced grain coarsening in severe plastic deformed low carbon steel. Scripta Materialia, 86 (2014), pp. 36 – 39.

[5] HILSER, O., RUSZ S., SALAJKA M., CIZEK L. Evaluation of the deep – drawing steel sheets processed by DRECE device. Archives of Materials Science and Engineering. International OCSCO World Press, 2014. Vol. 68, Issue 1, pp. 31 – 35. ISSN 1897 – 2764.