STUDY OF THE PROPERTIES OF UFG MATERIALS AFTER THE APPLICATION OF NEW FORMING METHODS

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Abstract

Development of materials with ultra-fine-grained structure belongs at present to the front-end areas of research of materials and forming technologies in the whole world. Nano-structural materials in mechanical engineering, metallurgy, automotive, military and aerospace industry are applied. Research areas of SPD processes as ECAP and DRECE technology at the Department of mechanical technology VSB - Technical University of Ostrava are intensively developed. Forming process DRECE is an extrusion technology with limited cross-sectional reduction to achieve high degree of deformation of the suitable selected material. DRECE machine can unequivocally contribute to implementation of new production technology for strip sheets and rods made of non-ferrous metals and steels (as semi-finished products), which have substantially higher mechanical properties with preservation of their formability. Experiments with use of selected steels and brass were made on the DRECE machines to achieve grain refinement in the strip of sheet with dimensions 58 x 2 x 1 000 mm. Metallographic analysis of structure was made on optical microscope NEOPHOT 2 and mechanical properties of studied samples by tensile test and Vickers hardness method were tested.

Keywords: DRECE method, severe plastic deformation, steel and brass strip sheets and rods, structure, mechanical properties

1. INTRODUCTION

At present numerous many scientific and research working sites in industrially developed countries deal with research and technology of ultra-fine grained (UFG) materials and nano-materials. Several principles of technological processes are examined and their influence on the micro-structure of materials and on operating conditions of the process. The cited literary sources indicate the best-known and the most frequently used severe plastic deformation (SPD) technologies. All research activities dealing with these technologies are in the state of basic and applied research. Possibility of their application in selected fields of industrial production is being verified. An integral trend of development works, regardless of the investigated technology, is to optimise the forming process in order to maximise the volume of processed material in combination possibility of its use in the industrial practice - as a continuous production process. For ensuring the general implementation of the UFG materials into industrial practice this direction of development is not only logical, but also highly desirable. Most frequently used and new developing methods for production of UFG materials describes many authors [1 - 7]: Research areas of SPD processes as ECAP and DRECE technology at the Department of mechanical technology VSB - Technical University of Ostrava are intensively developed.

The process DRECE is similar to the DCAP process. Scheme of DRECE process is shown in **Fig. 1**. In spite of the fact that deformation is not achieved by perfect simple shear, both numerical analyses and experimental observations showed that simple shear is a dominant manner of deformation in the course of DCAP. Shear deformation input into the sample was distributed comparatively uniformly along the full width, with the exception of regions close to the lower surface of the strip. Experimental results agree completely with the results obtained by mathematical

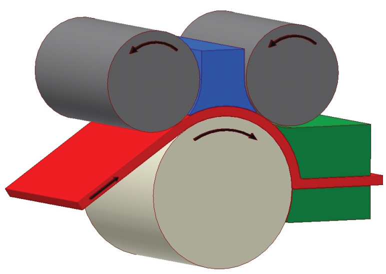
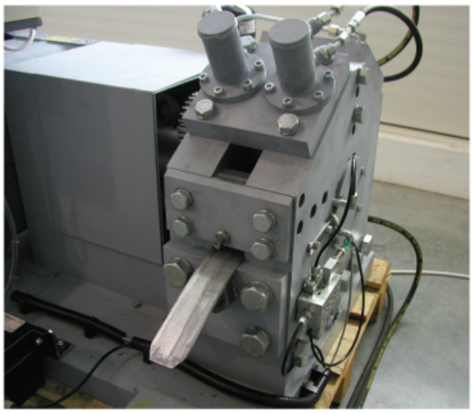


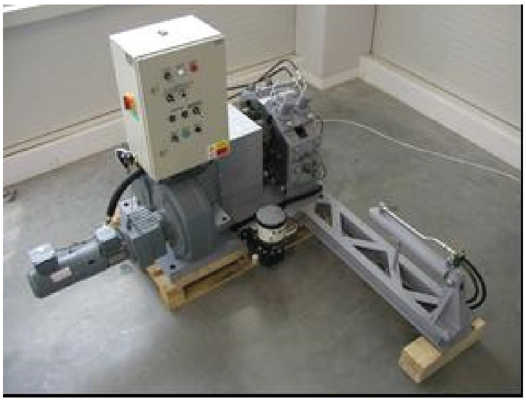
Fig. 1 Scheme of DRECE process

analyses with use of finite-element method [4, 8]. It is obvious from experimental results that different shear deformations occur near the lower surface. This uneven deformation occurs at the place, in which the work sample does not touch the tool.

Two prototype of equipment was put into trial operation at the working site of the VSB - Technical University of Ostrava, Department of Mechanical Technology [9]. **Fig. 2 a, b** gives an overall view of the prototypes of this equipment. It consists of the following main parts: gear of the type Nord with electric drive, disc clutch, feed roller and pressure rollers with regulation of thrust, forming tool made of the steel grade Dievar. Strip with dimensions 58 × 2 × 1000 mm was fed into the working space and it was pushed by the feed roller with help of pressure rollers through the forming tool without change of its cross section. Repeated plastic deformation realised in this manner brought substantial refinement of structure. During the trial operation the first experiments were made, followed by their evaluation. On the basis of these works some modifications of design is proposed.



a)



b)

Fig. 2 Machine DRECE a) for strip sheets processing, b) for rods processing

During testing period it was necessary to solve some problems about progress of the forming process - to solve problems about finding a suitable surface roughness of support cylinders, then to reduce warp and jamming of sheet during the process. Also a new geometry of forming tool is designed.

All the works related to testing period of the prototype had been performed during year 2009 and now the equipment is fully used for many experiments about optimization the forming process to ensure its high effectivity and for obtaining the highest quality of material output.

It is not possible to publish more detailed technical data as this equipment is patent protected. Another important structural elements of the DRECE machine consisted in designing of the suitable relation of size of the feed roller and pressure rollers, determination of guides between the entry of strip of sheet into the tool (top part of the tool) and at the entry of strip of sheet into the deformation zone (lower part of the tool).

2. EXPERIMENTAL MATERIALS, PROCEDURES AND RESULTS

The strip of sheet of AlMn1Cu alloy with dimensions 58 x 2 x 1000 mm and austenitic Cr-Ni steel as rod with diameter 7 mm and 1000 mm length was used for investigation. Strip of sheet form AlMn1Cu alloy and austenitic Cr-Ni steel was extruded through the DRECE equipment. In the case of AlMn1Cu alloy 8 passes and in the case of austenitic Cr-Ni steel only 2 passes were realized from the reason hardening of steel. Hardness HV10 and mechanical properties (yield strength $R_{p0.2}$, ultimate strength R_m and ductility A_{80}, A_{50} respectively) were evaluated in initial state and after application of the DRECE process. All the tensile tests were performed according to the ISO 6892-1 with using standardized test-pieces according to Annex D.

Investigation was completed by metallographic evaluation of micro-structure of selected samples. The chemical composition of AlMn1Cu alloy is given in **Table 1** and austenitic Cr-Ni steel shows the **Table 2.**

Table 1 Chemical composition of AlMn1Cu alloy

Chemical elements	**Si**	**Fe**	**Cu**	**Mn**	**Zn**
wt [%]	0.6	0.7	0.2	1.5	0.1

Table 2 Chemical composition of austenitic steel

Chemical elements	**C**	**Si**	**Cr**	**Mn**	**Ni**	**P**	**S**
wt [%]	0.018	0.36	18.15	1.50	8.05	0.034	0.020

Specimens of strip sheet AlMn1Cu alloy after extrusion process for example are shown in **Fig. 3.**

Fig. 3 Specimens of strip sheet AlMn1Cu alloy after the 8th pass through DRECE machine

2.1. Hardness evaluation of strip of sheet by Vickers (HV10) method

Hardness evaluation HV10 was performed with use of hardness tester HPO 250 on cross section cut from the samples at the place of measurement in initial state and on the strips after the 2nd, 4th , 6th and 8 th pass (for AlMn1Cu alloy see **Table 3** and for austenitic Cr-Ni steel (see **Table 4**). It is evident from **Table 3**, that the average hardness value increased significantly after the 2nd pass and slightly after 4th pass. This has confirmed that number of passes exceeding 4 has no significant influence on increase of hardness. The achieved highest value 135 (HV10) is higher about 45 % in comparison to the hardness value in initial state. This has confirmed correct functionality of the DRECE method. In the case of austenitic steel the average hardness value increases evenly.

Table 3 Average values of hardness of AlMn1Cu alloy

Number of passes	**Hardness HV10**
IS	41
2nd	52
4th	60
6th	61
8th	66

Table 4 Average values of hardness of austenitic Cr-Ni steel

Number of passes	**Hardness HV10**
IS	266
1st	293
2nd	326

2.2. Evaluation of mechanical properties by tensile test

Table 5 summarises the results of mechanical properties of AlMn1Cu alloy and **Table 6** summarises the results of mechanical properties of the austenitic steel.

Table 5 Results of tensile test of AlMn1Cu alloy

Number of passes	$R_{p0,2}$ [MPa]	R_m [MPa]	A_{80} [%]
IS	115	131	22
4th	135	163	10
6th	152	173	14
8th	152	171	13

Table 6 Results of tensile test of austenitic Cr-Ni steel

Number of passes	$R_{p0,2}$ [MPa]	R_m [MPa]	A_{80} [%]
IS	220	947	47
1st	245	1074	31
2nd	268	1207	16

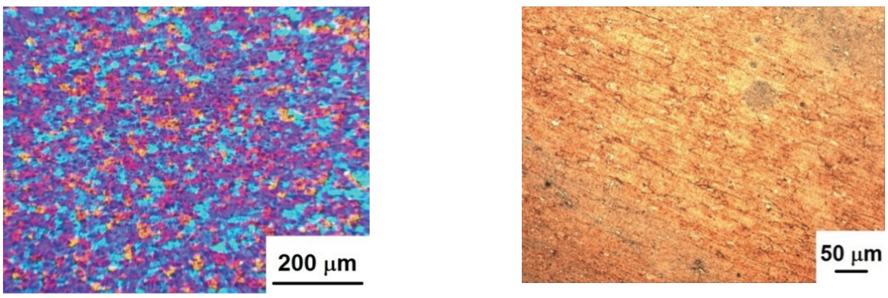
As it is seen from these tables the yield stress and ultimate tensile stress after DRECE processing are increased while the elongation is decreased. In the case of AlMn1Cu alloy after the 6th pass increasing of these values is minimal.

2.2. Metallographic analysis

Metallographic analysis was made on optical microscope NEOPHOT 2 for obtaining orientation information, as to whether grains were refined. Structure was analysed on the cross section of the sheet.

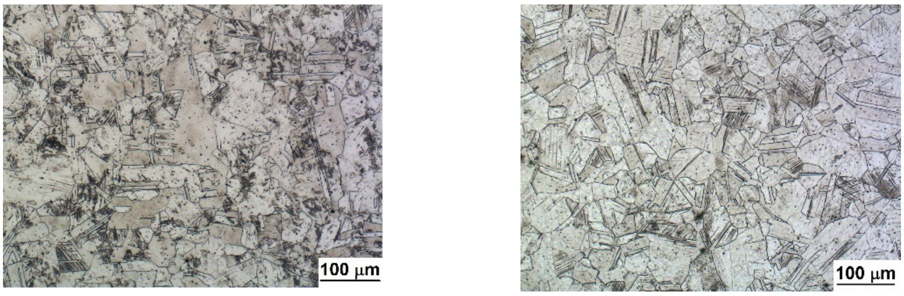
Altogether 8 passes were made through the DRECE tool. Comparison was made of the initial state and of the state after the 6th pass. Microstructures of $AlMn_1Cu$ alloy samples are shown in **Fig. 4** and microstructure of austenitic steel are shown in **Fig. 5.**

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. The results of experiments can be used in the study of other types of steels [10].



a) b)

Fig. 4 Microstructure of the AlMn1Cu alloy a) initial state, b) after the 6th pass



a) b)

Fig. 5 Microstructure of the austenitic Cr-Ni steel
initial state, b) after the 2nd pass

3. CONCLUSIONS

Both types of equipment mentioned above are suitable for experimental verification of structure refinement, bringing substantial enhancement of mechanical properties in all types of metallic materials, but particularly in the alloys of non-ferrous metals. The alloys of non-ferrous metals based on Al, Mg, Ti, etc. are at present broadly used namely in automotive industry, aerospace industry and lately also in medical practice (dental implants, prosthetics). The applications in power engineering bring an increase of conductivity in high-voltage transmission lines, increased resistance to corrosion resulting from structure refinement, and particularly the possibility of storage of hydrogen in UFG materials. The above mentioned devices will be fully usable also for laboratory verification of production of materials and blanks with such properties.

Creation of UFG structure in the strip of sheet is closely connected to the design of suitable geometry of the forming tool, appropriately dimensioned power unit and control system enabling setting of various values of peripheral velocities. From the viewpoint of forming parameters higher number of passes will bring considerable strengthening of the formed material. According to the degree of the obtained results of extrusion of the sheet made of brass it is possible to state that the equipment is fully functional.

The DRECE method for the rods 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 structure in the case of metals.

From the viewpoint of forming parameters higher number of passes will bring considerable grain refining and strengthening of the formed material.

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] GUTKIN M.YU., OVIDKO I.A. and PANDE, C.S. Theoretical models of plastic deformation processes in nanocrystalline materials. Reviews on Advanced Materials Science, September 2001, Vol. 2, p. 80 - 102.

[2] KOBAYASHI M. at ALL. Research and Development of Superplastic Materials „Recent Progresses and Future Prospects“. Metallurgical Transactions 18A, 1987, pp. 685-695.

[3] IWAHASHI Y. at ALL. Principle of equal-channel angular pressing for processing of ultra-fine grained materials. Scripta Materialia, Vol.35, 1995, pp.143-147.

[4] BOURKE M. A. M. at ALL. Finite element analysis of the plastic deformation zone and working load in equal channel angular extrusion. Materials Science and Engineering, July 2003, Vol. 49, pp. 185 - 204.

[5] RUSZ S., ČÍŽEK, L. and KLOS, M. Modelling of severe plastic deformation at ECAP technology process. In. Trends in the Development of Machinery and Associated Technology: International Research/Expert Conference. Istanbul, Turkey, 26-30 August, 2006, pp. 1249-1252.

[6] VALIEV, R. Recent developments of severe plastic deformations techniques for processing bulk nanostructured materials. Materials Science Forum A 579 (2008) p. 1-14.

[7] MICHENKA V., GOTTWALD M., MALANÍK K. and RUSZ S. Research of influence of extreme deformation conditions on metal sub-microstructure and development of testing methods for evaulation of their technological properties. In. METAL 2009: 18th International Conference on Metallurgy and Materials. Ostrava: TANGER, 2013. Ostrava: TANGER, 2009, pp. 1-9 (CD).

[8] LEE J.C., SEOK H.K. and SUH J.Y. Microstructural evolutions of the Al strip prepared by cold rolling and continuous equal channel angular pressing. Acta Materialia 50 (2002), pp. 4005-4019.

[9] RUSZ S. Progress report of the project MPO No. 2A-1TP1/124 for the year 2009, pp. 1 -38.

[10] CIESLA M., FINDZINSKI R. and JUNAK G. Durability of tube bends made of the 14MoV6-3 steel under low-cycle fatigue conditions and creep at a temperature of 500°C. Solid State Phenomena, Vol. 226 (2015) pp. 79-86