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POSSIBILITIES OF APPLICATION METHODS DRECE IN FORMING OF NON-FERROUS METALS

MOŻLIWOŚCI APLIKACYJNE METODY DRECE DOTYCZĄCE ODKSZTAŁCANIA METALI NIEŻELAZNYCH

Device “DRECE - Dual Rolls Equal Channel Extrusion” is used for production of metallic materials with very fine grain size (UFG). During the actual forming process the principle of severe plastic deformation is used. Metallic strip with dimensions 57×2×1000 mm 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 DRECE device is also being verified from the viewpoint of achievement of a UFG structure in a blank of circular cross-section (wire) with diameter of ϕ 8 mm × 1000 mm.
Keywords: severe plastic deformation, grain refinement, mechanical properties, formability, new design of forming tool.

Urządzenie „DRECE - Dual Rolls Equal Channel Extrusion” znajduje swoje zastosowanie do wytwarzania metali o strukturze ultradrobnoziarnistej (UFG). W trakcie procesu wytwarzania stosuje się metodę wielokrotnej deformacji. W urządzeniu założona jest metalowa taśma o wymiarach 57×2×1000 mm. Podczas procesu formowania, główny cylinder we współdziałaniu z dociskowym wałkiem wytłaczającym odkształca materiał bez zmiany wymiaru przekroju poprzecznego taśmy. W ten sposób uzyskuje się znaczne rozdrobnienie ziarna przez wielokrotne odkształcenie plastyczne. Metoda ta jest wykorzystywana do różnego rodzaju materiałów metalowych, metali nieżelaznych i ich stopów. Urządzenie DRECE jest również testowane pod kątem osiągnięcia struktury UFG w materiale o przekroju okrągłym (drut) o średnicy ϕ8 mm i długości 1000 mm.

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 [1,7,10,11]. 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 comprise the following technologies [1-7]:

- High Pressure Torsion
- Equal Channel Angle Extrusion
- Cyclic Channel Die Compression
- Cyclic Extrusion Compression
- Continuous Extrusion Forming
- Accumulative Roll Bonding
- Constrained Groove Pressing
- Thixoforging
- HPT – High Pressure Torsion
- DRECE

Research areas of SPD processes as ECAP and DRECE technology at the Department of mechanical technology VSB – Technical University of Ostrava are intensively developed [8].

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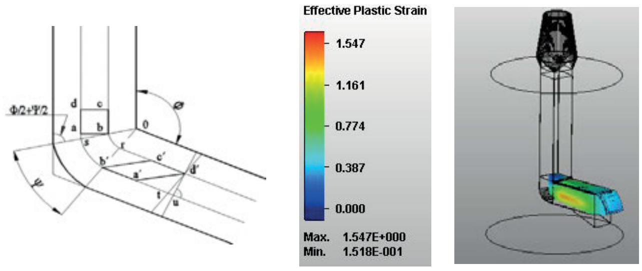
2. Research areas of SPD processes – developed at the Department of Mechanical Technology VSB – Technical University of Ostrava

2.1. The first area – Equal Channel Angular Pressing (ECAP process)

Fig. 1a explains schematically the principle of the ECAP technology, where two rectangular channels intersect mutually at an oblique angle *Φ* and shows removal of small element of square section with dimensions given by the points a b c d, which changes after passage through the die due to effect of shear friction to the position defined by the point's a´ b´ c´ d´. The pressing can be lead through a square configuration of the channel [1-2].



a) b) c)

Fig. 1. a) Principle of the ECAP, where *Φ* is the angle of transition of two channels and *Ψ* curvature of transition, b) FEM strain simulation for Al alloy (after the 1st pass through the ECAP tool)

This situation was considered already in the previous works of Inwahashi [3]. Quantity of friction against the channel wall was assigned to the angle Ψ. In practice this can be avoided by suitable lubricant. The samples are lubricated in such a way that friction effects are negligible. Under presumption that identical deformation is accumulated during each pass through the channel, it is possible to express the deformation intensity for N-cycles by Eq. (1) [1, 2].

$$\varepsilon_N = N \cdot \left[\frac{2 \cdot \cot\left(\frac{\Phi}{2} + \frac{\Psi}{2}\right) + \Psi \, \mathrm{cose}\left(\frac{\Phi}{2} + \frac{\Psi}{2}\right)}{\sqrt{3}} \right] \quad (1)$$

2.2. The second area - Dual Rolls Equal Channel Extrusion (DRECE process)

The process DRECE is similar to the DCAP process. Scheme of DRECE process is shown in Fig. 2. 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 analyses with use of finite-element method [4]. 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.

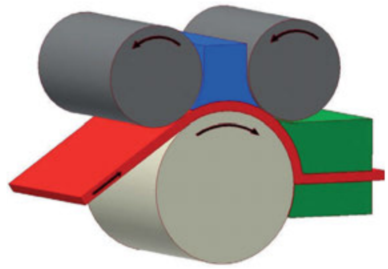


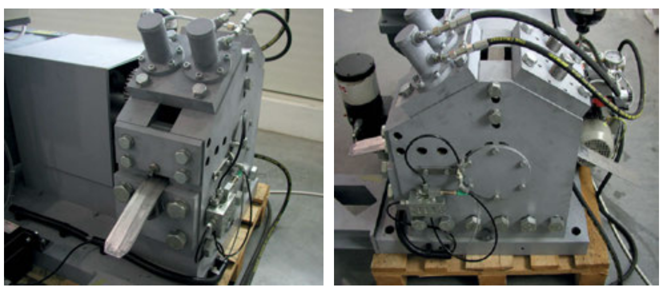
Fig. 2. Scheme of DRECE process

$$\varepsilon = \frac{2N}{\sqrt{3}} \cdot K^2 \cdot \cot\left(\frac{\text{EMBED Equation.3}}{2}\right) \quad (2)$$

$$\varepsilon = \frac{\frac{2}{\sqrt{3}}}{ln(1-R)} \quad (3)$$

The Eq. (2) gives an efficient deformation obtained by the DCAP, which is expressed in dependence on the number of passes (N) and relation of thicknesses (K). On the other hand the Eq. (3) represents rolling expressed in relation to the reduction ratio (R). Investigation of changes of hardness in dependence on efficient deformation established slightly lower hardness in the sample after DCAP than in the sample after cold rolling [9].

During 2009 a prototype of this equipment was put into trial operation at the working site of the VSB Technical University of Ostrava, Department of Mechanical Technology [10]. Fig. 3a and Fig. 3b gives an overall view of the prototype 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 were proposed.



a) **b)**

Fig. 3. Prototype equipment DRECE for extrusion of strip sheet metal a) lateral view of the equipment b) front view

3. Experimental material and procedures

Experiments with use of the formed structural material – brass (Cu-Zn 65/35 weight %) and AlMn1Cu alloy were made on the DRECE machines in order to achieve grain refinement in the strip of sheet with dimensions 58 × 2 × 1000 mm. The chemical composition is given in TABLE 1.

TABLE 1

Chemical composition of AlMn1Cu alloy (wt %)

Chemical elements	Si	Fe	Cu	Mn	Zn	Al
[%]	0,6	0,7	0,2	1,5	0,1	rest.

Altogether maximum 6 or 8 passes were made through the DRECE tool. Each next pass was realized after rotation of sheet with angle 180°. Lubricant GLEIT – μ HP 515 for cold forming before each pass was used. The extruded samples of brass after all passes were then cut from sheets into individual series for manufacture of individual testing specimens for metallographic evaluation and mechanical tests (hardness and tensile tests).

Fig. 4a show the strip of sheet AlMn1Cu alloy before the 1st pass and Fig. 4b show the strip of sheet AlMn1Cu alloy after the 4^{th} pass.

Fig. 4a. the strip of sheet AlMn1Cu alloy before the 1^{st} pass

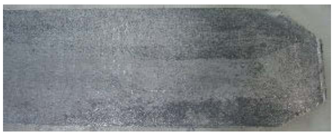


Fig. 4b. the strip of sheet AlMn1Cu alloy after the 4^{th} pass

4. Results and discussion

4.1. Mechanical properties

Mechanical properties of studied samples of brass and AlMn1Cu alloy were tested by Vickers hardness method on the HPO 250 testing device and tensile test on the Inova TSM 50 testing machine was realized. Results of Vickers hardness test of brass are shown in the TABLE 2 and AlMn1Cu alloy in the TABLE 3.

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 4^{th} passes. After the 4^{th} pass the value of hardness stays nearly the same.

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

Results of tensile test of brass are shown in TABLE 4

As it is seen from this table the yield stress and ultimate tensile stress after DRECE processing are increased to 4^{th} pass while the elongation is decreased.

Results of tensile test AlMn1Cu alloy are shown in TABLE 5.

As it is seen from this table the yield stress and ultimate tensile stress after DRECE processing are increased to 4^{th} pass while the elongation is decreased. In the case of 6th and 8^{th} passes used values change minimally.

TABLE 2

Average values of hardness of brass

Number of passes	Hardness HV5
IS	93
2nd	127
4th	150
6th	160

TABLE 3

Average values of hardness of AlMn1Cu alloy

Number of passes	Hardness HV5
IS	41
2^{nd}	52
4^{th}	60
6^{th}	61
8^{th}	66

TABLE 4

Results of tensile test of brass

Number of passes	Rp0,2 [MPa]	Rm [MPa]	A80 [%]
IS	238	350	48
2^{nd}	305	392	44
4^{th}	375	450	14
6^{th}	361	438	14

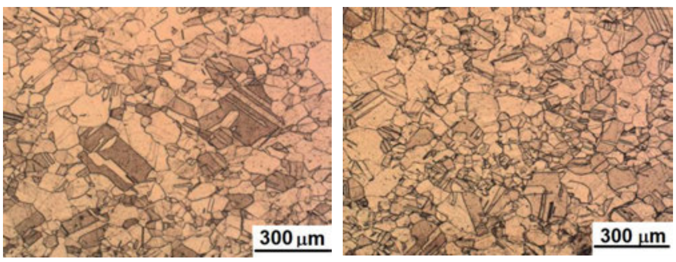
TABLE 5

Results of tensile test of AlMn1Cu alloy

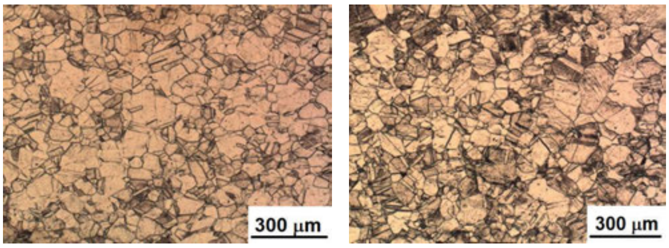
Number of passes	Rp0,2 [MPa]	Rm [MPa]	A80 [%]
IS	115	131	22
4^{th}	135	163	10
6^{th}	152	173	14
8^{th}	152	171	13

4.2. Metallographic analysis

Metallographic analysis was made on light microscope NEOPHOT 2. After usual metallographic preparation the samples were chemically etched. Microstructures the samples of brass are shown in Fig. 5.



a) sample of initial state b) sample after the 2^{hd} pass

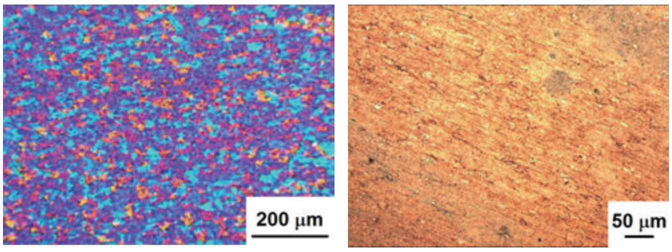


c) sample after the 4th pass d) sample after the 6th pass

Fig. 5. Microstructure the samples of the brass after DRECE processing

Fig. 5a shows microstructure of initial state sample of brass. This microstructure consists of grains in agreement with the fact that this material was formed before the DRECE processing. Grain size reached the value G4 according to ASTM. Microstructures of brass samples after passes through the DRECE tool are shown in Figs. 5b, c, d. As it can be seen from these micrographs, refining of grains after each pass was only small. Grain size reached the value from G5 to G6 according to ASTM.

Microstructures of AlMn1Cu alloy samples are shown in Fig. 6.



a) b)

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

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.

5. Conclusion

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.

Prototype equipment for production of UFG structure in a strip of sheet made of non-ferrous metals have been designed, with subsequent possibility of deformation also of steel sheets with thickness of 2 mm. This process involves primarily creation of sufficient number of shear systems with different orientation in crystallographic lattice. 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 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 structure in non-ferrous 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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