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Development of unconventional forming methods

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Materials

ABSTRACT

Purpose: Paper presents results of progress ECAP processing method for UFG structure reached (gained). The properties and microstructure are influenced by technological factors during application ECAP method.
Design/methodology/approach: Summary of methods studied on Department of technology at Machining faculty of VŠB-TU Ostrava through of co-operation with Institute of Engineering Materials and Biomaterials, Silesian University of Technology is presented.
Findings: Achievement of ultra-fine grained structure in initial material leads to substantial increase of plasticity and makes it possible to form materials in conditions of „superplastic state". Achievement of the required structure depends namely of the tool geometry, number of passes through the matrix, obtained deformation magnitude and strain rate, process temperature and lubrication conditions. High deformation at comparatively low homologous temperatures is an efficient method of production of ultra-fine grained solid materials. The new technologies, which use severe plastic deformation, comprise namely these techniques: High Pressure Torsion, Equal Channel Angular Pressing = ECAP, Cyclic Channel Die Compression = CCDC, Cyclic Extrusion Compression = CEC, Continuous Extrusion Forming = CONFORM, Accumulative Roll Bonding, Constrained Groove Pressing.
Research limitations/implications: Achieved hardness and microstructure characteristics will be determined by new research.
Practical implications: The results may be utilized for a relation between structure and properties of the investigated materials in future process of manufacturing.
Originality/value: These results contribute to complex evaluation of properties new metals after application unconventional forming methods. The results of this paper are determined for research workers deal by the process severe plastic deformation.
Keywords: Metallic alloys; ECAP method; Mechanical properties; Microstructure

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1. Introduction

Numerous technological forming processes achieve deformations, which are substantially higher than those achieved during the tensile test. One of the turbulently developing areas is the development of nano-structural materials, which is currently one of the priority areas of scientific research in the field of materials and forming technologies all over the world. This concern in particular forming of non-ferrous metals and their alloys. At the same time they bring significant reduction of manufacturing costs for products made from these materials. Importance of their use, particularly in the automotive industry, military and aerospace industries is ever increasing. Major world car makers, such as Opel, Audi, Jaguar, Ford, Fiat, Volvo and Toyota are at present developing an entirely new concept of fuel-efficient cars with a high share of aluminium and its alloys. Al alloys with ultra-fine structure serve as basic, initial semi-product. Their development uses technologies for achievement of nano-structural materials. Achievement of ultra-fine grained structure in initial material leads to substantial increase of plasticity and makes it possible to form materials in conditions of „superplastic state“. Achievement of the required structure depends namely of the tool geometry, number of passes through the matrix, obtained deformation magnitude and strain rate, process temperature and lubrication conditions. High deformation at comparatively low homologous temperatures is an efficient method of production of ultra-fine grained solid materials. The new technologies, which use severe plastic deformation, comprise namely these techniques: High Pressure Torsion, Equal Channel Angular Pressing = ECAP, Cyclic Channel Die Compression = CCDC, Cyclic Extrusion Compression = CEC, Continuous Extrusion Forming = CONFORM, Accumulative Roll Bonding, Constrained Groove Pressing [1-5].

The aim of this article is summaries the methods studied on Department of technology at Machining faculty of VŠB-TU Ostrava presented by Prof. Stanislav Rusz and Ass. Prof. Lubomír Čížek through of co-operation with Prof. Leszek A. Dobrzański, Institute of Engineering Materials and Biomaterials, Silesian University of Technology. This co-operation has roots in long time prolonged co-operation of Prof. Vladimír Dembovský and Prof. Leszek A. Dobrzański [5-7].

2. HPT - High pressure torsion

Diagram of this method is shown in Fig. 1. The sample in the form of small block is brought between two punches with cylinder recess, the height of which is slightly smaller than that of the sample. Rotation of the top punch creates by friction in the formed sample a moment necessary for deformation of the sample. In the first place pressure is propagated in the formed sample and at the same time during the final twisting of the sample the mat is rammed [8-10]. Friction conditions in material change during the ramming process.

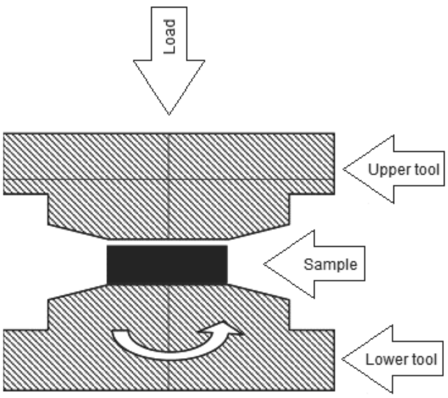


Fig. 1. Schematic illustration of the HPT method

In order to keep this effect at the possibly lowest level the friction surfaces between both punches are reduced to minimum by grinding of conic surfaces on them. Magnitude of deformation achieved at experiments by the HPT method was higher than 1000% on all various metallic materials, and at the same time not a single crack of the sample occurred.

3. CEC - cyclic extrusion compression

Principle of this method consists in the fact that material is in the first stage extruded and in the final stage it is compressed. As a result of this the sample keeps its original shape, as is the case in all other procedures. Both steps of deformation can be realised by processes shown in Fig. 2. Material is in the first stage of the forming process extruded in a cylindrical channel. As a result of simultaneous effect of back pressure the material after reduction is compressed again and it thus fills again the original cross-section of the channel (a). By changing shape of the pressed material from one side of reduction to another one it is possible to achieve thus here identically high deformation. In the second variant (b) a wide specimen is compressed into the reduced channel (usually of cylindrical shape) and it is then compressed with use of back pressure again from the reduced into the wide channel. Due to sufficiently high widening of the tool no cracks are formed in the deformation; zones.

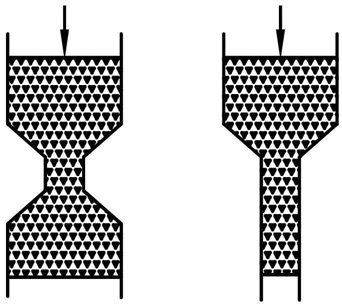


Fig. 2. Schematic illustration of the CEC method

4. CCDC - cyclic equal channel die compression

The principle of the technology of cyclic equal channel die compression is shown in Fig. 3.

Cylindrical specimen is rammed in a channel of circular cross-section. After ramming it is turned by 90° and rammed again. Big number of slip planes is formed and thus high degree of deformation is achieved with simultaneous high refining of grain of the formed material.

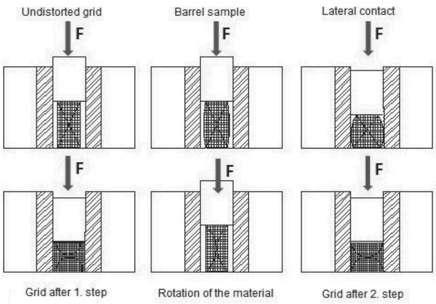


Fig. 3. Schematic illustration of the CCDC method

5. Conform - continuous extrusion forming

The method CONFORM was originally developed for continuous extrusion, but it was not used due to problems with wear. Schematic diagram of this process is shown in Fig. 4. This method was taken up again and attempts were made to achieve a very high degree of deformation by its repeated use [9]. The process can be described in a simplified manner as a continuous ECAE process, where the compressive need not be exerted by punch as in the case of ECAE, but by the feed cylinder.

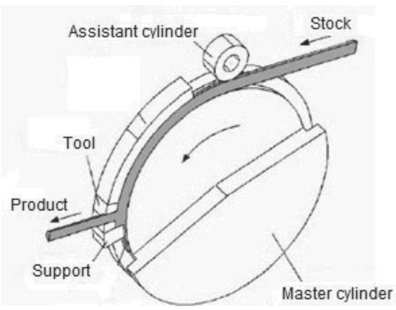


Fig. 4. Schematic illustration of the Conform method

6. ARB - accumulative-roll-bonding

The plate is in this process cut to two equally large parts, one part is thoroughly cleaned, the parts are put one onto another and then they are re-rolled to the original width. This rolling should ensure a diffusion welding of both plates, that's why this process requires mostly higher temperatures and low strain rates [16]. The plate has after processing again the initial dimensions, it can be therefore cut again to two equally large parts and the process can be repeated as many times as needed. Schematic diagram of this method, which is currently intensively investigated in Japan, is shown in Fig. 5. At present experiments are carried out attempting production of finely crystallised steel and aluminium alloy.

Disadvantage of this method is considerable heterogeneity of structure connected with an elongated shape of the deformed grain. Apart from this the contact surface of both plates must be carefully cleaned before each rolling, which increases production costs.

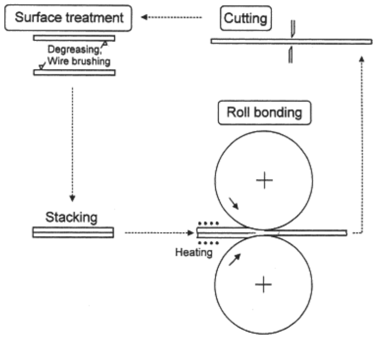


Fig. 5. Schematic illustration of the ARB method

7. CGP - constrained groove pressing

CGP is another process, in which straight blanks are exposed to high deformation without changing the shape of the plate the process CGP is shown in Fig. 6. It is possible to achieve high deformation in a cyclical manner by asymmetric shape of the die. The blank is straightened in the next step a d the whole process is cyclically repeated. Similarly, it is possible to create in this manner on straight surface highly deformed border layers.

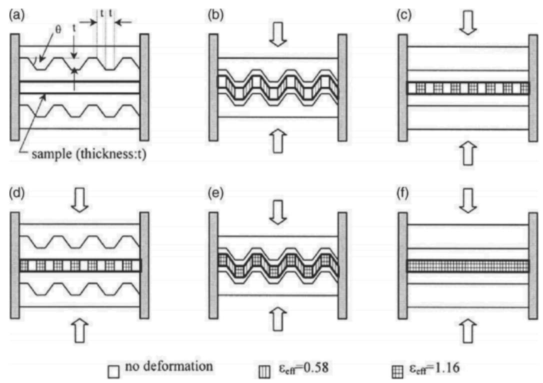


Fig. 6. Schematic illustration of the CGP method

8. ECAP - equal channel angular pressing

Application of the ECAP method makes it possible to obtain an ultra-fined grain in larger volumes, when the initial cross-section does not change during extrusion. It finds an important of use namely in automotive industry and also in military and aerospace industries. The products manufactured by this technology meet the basic pre-requisites for their subsequent use at super-plastic forming. Diagram of the Equal Channel Angular Pressing (ECAP) method is shown in Fig. 7.

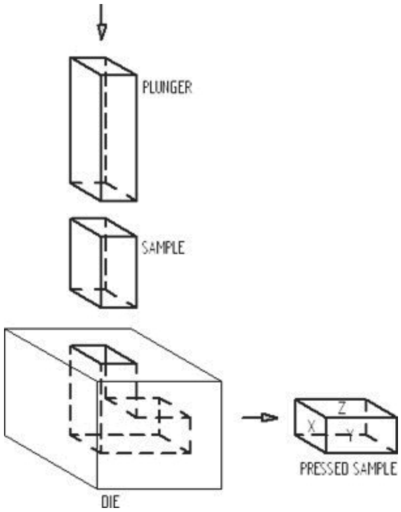


Fig. 7. Schematic illustration of the ECAP method

Plastic deformation is a complex process depending on large number of factors, such as deformation temperature T, especially in relation to the melting temperature T_t (relation T/T_t gives the homologous temperature), and the grain size d_z, rate of deformation $\dot{\varepsilon}$, magnitude of stress at deformation σ, particularly in relation to magnitude of the Young's modulus E (σ/E represents homologous stress), but also on density of structural defects (in particular of dislocations), on purity and others. Deformation realised by the cold ECAP technology depends significantly on the last named factors [10]. As a result of non-homogeneity of deformation at the ECAP process (selected planes and directions of slip) the increment of internal energy at various places of the formed alloy is also different. For example the value of internal energy is different ion the slip planes, at the boundaries and inside the grains. It is possible to observe higher internal energy also in proximity of precipitates, segregations and hard structural phases. For usual technologies, pure metals, mean magnitude of deformation and temperatures the value of stored energy is approx. 10 $J.mol^{-1}$. At cold extrusion the density of dislocations increases with the magnitude of plastic deformation, as well as concentration of vacancies and overall surface of walls of the cell structure.

Principle of the ECAP method

As it was already mentioned above, high plastic forming is achieved by extrusion of the specimen through the channel (see Fig. 7). The machined specimen is inserted into the L-shaped matrix. For the case when the angle between two parts of the L-shaped matrix is equal to 90°, the test specimen is exposed to shear at the moment of transition from one part into another. It is evident that specimens are extruded in the channel without any change of their dimensions in the cross-section. By this the given process differs from majority of usual methods of metal forming, such as rolling and extrusion, which are accompanied by reduction of cross-section of the processed piece, and where the deformation is achieved by the change of the initial cross-section. In practice it is appropriate to define individual planes inside the specimen extruded by the ECAP technology, namely the plane X perpendicular to the longitudinal axis, and the planes Y and Z that are parallel to the lateral and top face of the specimen.

Deformation of the sample at its individual places of passage inside the die depends particularly on the angle Φ between two separated parts of the channel inside the matrix. Dependence on the angle Ψ of the arc of curvature at the place, where both channels intersect, is also very important (see Fig. 8).

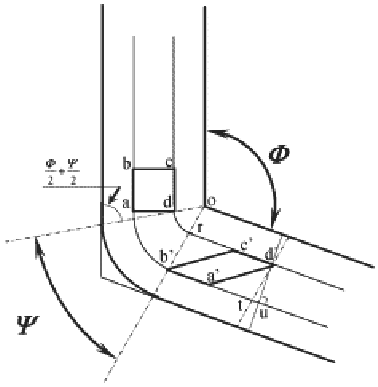


Fig. 8. Dependence on the angle Ψ of the arc of curvature

Due to the fact that surface of cross-section of the specimen does not change at individual places during passage through the channel, it is evident that repeated extrusion is made in order to achieve a very high degree of deformation. In practice it is possible to rotate the specimen between individual extrusions, which activates different shear systems.

Several research works were focused on; econ of the effect of rotation of the specimen between individual passes [8].

9. DCAP (C2S2) - dissimilar channel angular pressing

Cost efficiency at production of high quality sheets from Aluminium alloys was already for a long time the main criterion at their production. The rolling process is among several other technologies used very broadly as technological process for manufacture of various types of sheets from cast plates. Achievement of necessary properties of sheets made of Al alloys, such as mechanical properties and formability, requires usually reduction of thickness of cast plates in the range from 80 to 90% by repeated rolling. This process is less efficient, since it requires expensive manufacturing equipment, consisting of cold and hot rolling mill and equipment for heat treatment.

Casting of thin plates, combined with the following rolling, lead successfully to reduction of production costs of sheets and it is commonly used for production of sheets. During last years procedures were developed for decrease of reduction of thickness of strips at individual passes through the rolling stands. The strips are made from the cast strip steel with thickness from 2 to 5 mm. The strips can be produced at comparatively high a rate, which entails another reduction of costs. In spite of possibilities of cost reduction by the above technology, some other problems occurred. They comprise e.g. complex control of micro-structure of the cast strips, which is necessary for achievement of the required strength and formability. It is caused by the fact that it is impossible to perform further reduction of cast strips by rolling, since the initial thickness is too thin. As a result the control of micro-structure after rolling is sometimes very difficult or even impossible, due to too small thickness of the strips[1,8].

The above described method ECAP (Equal channel angular pressing) is in fact a process, which enables implementation of big deformations into materials without changing the cross-section of specimens. Thanks to appropriate channel geometry the deformation can be put into material during one passage through the tool. Surface of cross-section of the specimen does not change much before and after ECAP. It is also possible to apply multiple passes through the channel, which may be used for modification of material properties and to use these characteristics of the ECAP method as a basis for development of new forming technology, with help of which fine-grained materials with tailor-made properties will be produced [1]. It was impossible to apply the ECAP technology, used in previous studies, for forming of long and narrow samples, which was the main drawback for broader commercial use of this process. If the ECAP process is used for production of metallic strips in continuous cycle, it might be advantageous to modify it as new technology for production of strips from various materials with adapted properties at high quantity of production.

The new technology was called dissimilar channel angular pressing (DCAP) (original technological name was C2S2). This process makes it possible to manufacture metallic strips with adapted material properties by continuous process (rolling + ECAP technology). Change of properties of 1050 Al strips processed by the DCAP technology was analysed and results were compared with the results obtained at cold rolling

Diagram of DCAP equipment is shown in Fig. 9. The forming tool is represented by special feed cylindrical insert and control cylinder with diameter of 10 cm. In order to improve the feed force of the rolls their surfaces were modified by removal of chips of 0.3 mm (feed of strips into the DCAP equipment). Priority of feed is application of synthetic oil on the surface of strip for reduction of friction between the strip and matrix wall during forming. Although the feeding rate depends on dimensions of specimen and angle in the channel, the usual setting is from 5-50 mm/min.

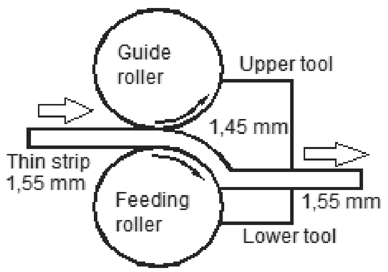


Fig. 9. Schematic illustration of the DECAP method

The matrix has two channels with different thickness; thickness of the outer channel (1.55 mm) is slightly bigger than that of the inner channel (1.45 mm), as it is shown in Fig. 10. Angle of the channel Φ, which is created by an intersection of the outer and inner channel, can be increased from 100° to 140° with an angle of curvature Ψ = of approx. 0°. Initial thickness of the strip is 1.55 mm, it is fed by the feed roller and formed to the thickness of 1.45 mm, and it travels then through the die towards the forming zone. The strip is then pushed through the forming zone, where outer and inner channels intersect and it comes out of the channel with preservation of the initial thickness of 1.55 mm.

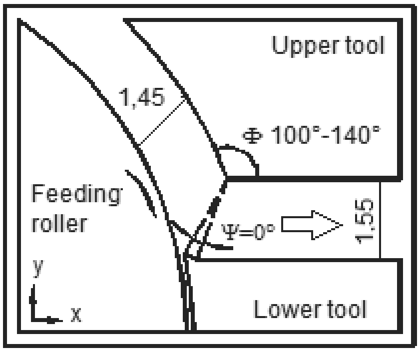


Fig. 10. Angle of the channel Φ

By feeding the specimen by the feed roller instead of feeding material with use of the hydraulic press punch enabled not only continuous forming, but also production of metallic strips of various final thicknesses [14,16,17].

10. New concept methods

Twist Extrusion (TE - extrusion with built-in helix)

TE is based on extrusion of the sample of prismatic cross-section through the tool with the profile consisting of two prismatic parts separated by a helical part (Fig. 11). Cross-section at TE remains unchanged. This feature makes it possible to extrude the sample repeatedly in order to accumulate the strain needed to change the micro-structure and mechanical properties of the sample material.

Technological possibilities of the TE method compared with the ECAP method:

- Magnitude of termination of the deformed area of the sample at the input and output part of the sample is much lower in TE than in ECAP. This is a feature, which is very important for repeating of passes [9,14].
- Change of the sample profile occurs at the central part of the axial channel [9,13,15,18].
- TE can be easily installed on the standard equipment of the press by replacement of traditional tools by the tool with rotary channel (helix).
- Tool (TE) does not change the direction of movement of the sample, which enables its simple inclusion into the existing

tools on the presses and thus integration of this equipment into a production line [9,19,20].

New concept of the forming tool - called ECAP + TE (ECAP tool with built-helix in the horizontal channel - see Fig. 12)

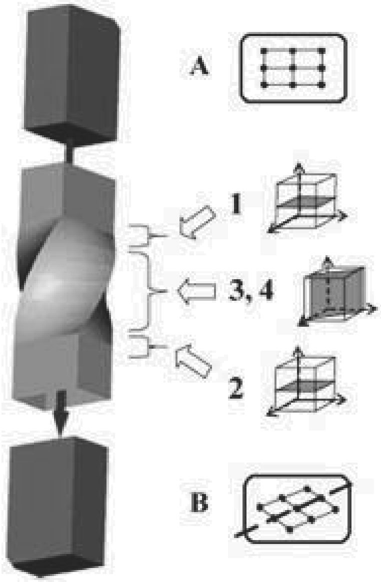


Fig. 11. Principle of the Twist Extrusion Process

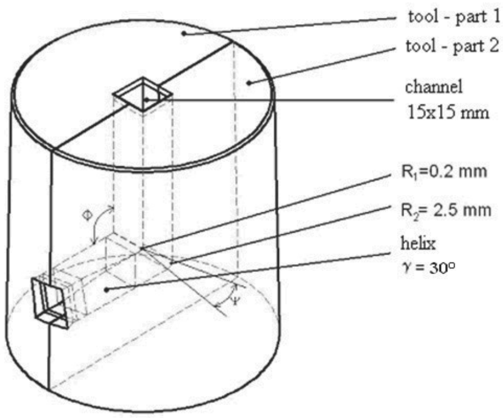


Fig. 12. Insert of the ECAP tool with built-in helix

This new approach will make it possible to significantly increase the efficiency of the process of severe plastic deformation (SPD). The material will be strengthened very intensely, allowing us to achieve a high degree of deformation of material at a lower number of passes through the forming tool. At the same time high homogeneity of the structure will be achieved. We want to realize the verification of the results in collaboration with the Zilina University, Faculty of Mechanical Engineering. The selected type of material will be pressed through the ECAP tool with back counter-pressure. The principle of the method is shown in Figure 13. The results achieved by both methods will be mutually compared.

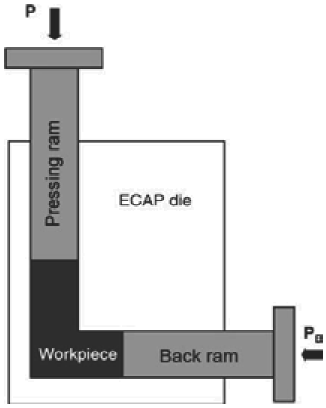


Fig. 13. Diagram ECAP + BP

Next fundamental objective of the research work will be verification of use of the DRECE method for development of ultra-fine grained (UFG) structure.

This case concerns flat forming of strip of sheet. Materials based on alloys of non-ferrous metals, as well as steels will be selected from the viewpoint of their subsequent use in industrial practice.

Principle of the process is shown in Fig. 14. Sheet of metal strip is fed into the forming tool feed by feeding roll and by two pressure rollers [21]. In the zone of deformation after individual passes and after turning of the sheet by 180° in the "X" axis a system of shear planes is formed, which allows the grain disintegration. This method seems to be very promising for a wider range of materials in terms of achieving a significant increase in their mechanical properties.

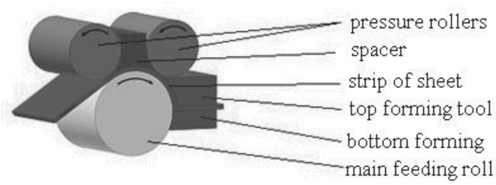


Fig. 14. Scheme of the DRECE method

11. Laboratory equipment

At the VSB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Mechanical Technology a new tool for the ECAP method was developed (change of geometry of the channel, allowing an increase in the degree of deformation at each pass), situated on the hydraulic press DP 1600 kN (see Fig. 15a,b). Thanks to the new geometry in comparison with the traditional tool the number of passes is reduced, while the efficiency of the SPD process is substantially enhanced, which also reduces the time necessary for obtaining the UFG structure in the tested materials. Dimensions of the formed semi-product are 15×15×60 mm. This design of construction has not yet been published in scientific professional journals. The mentioned working site has moreover developed also a unique DRECE device (Dual Roll Equal Channel Extrusion). This equipment is intended for extrusion of a strip of sheet with dimensions 58×2×1000 mm in order to achieve a significant refinement of the structure and high mechanical properties (see Fig. 16).

a)

b)

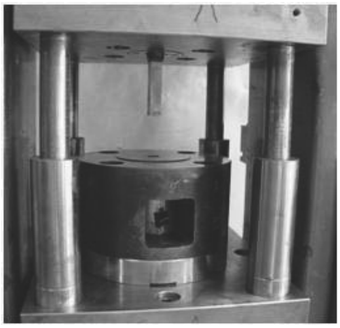
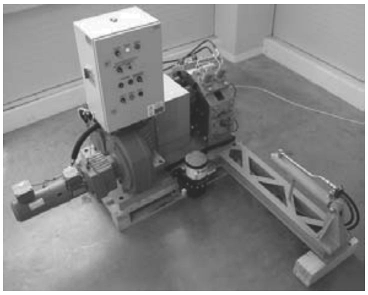


Fig. 15. Press DP 1600 kN with the ECAP tool, a) general view, b) detail of the forming tool

a)



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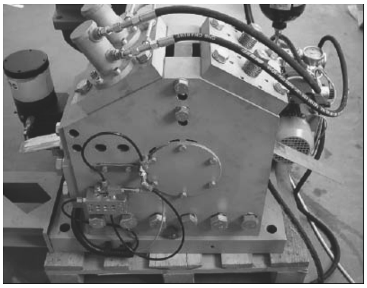

Fig. 16. DRECE Equipment a) general view, b) detail of the forming tool

12. Conclusions

The new concept methods equipment ECAP and DRECE is at the stage of verification and future works will verify the influence of technological parameters on the increase of efficiency of SPD process for obtaining of the UFG structure in non-ferrous metals.

According to the level of the obtained results on this equipment it is possible to state that the equipment is fully functional.

These results for new period of co-operation between Department of technology at Machining faculty of VŠB-TU Ostrava and Institute of Engineering Materials and Biomaterials, Silesian University of Technology.will be used.

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References

[1] M. Kobayashi, Research and development of superplastic materials, Recent progresses and future prospects, Metallurgical Transactions A 18 (1987) 685-695.

[2] J. Sinczak, W. Lapkowski, S. Rusz, Superplastic deformation of steel, Metallurgy and Foundry Engineering, 22/1 (1996) 41-48.

[3] M.Yu. Gutkin, I.A. Ovidko, C.S. Pande, Theoretical models of plastic deformation processes in nanocrystalline materials, Reviews on Advanced Materials Science 2 (2001) 80-102.

[4] S. Rusz, J. Bořuta, Plastometric testing middle and high-carbon steels, Ores And Non-Ferrous Metals 11 (1995) 454-456.

[5] L.A. Dobrzański, T. Tański, W. Sitek, L. Čížek, Modeling of mechanical properties magnesium alloy, Proceedings of the 12th Scientific International Conference on “Achievements in Mechanical and Materials Engineering” AMME’2003, Gliwice-Zakopane, 2003, 293-296.

[6] L.A. Dobrzański, T. Tański, L. Čížek, Influence of modification with chemical elements on structure of magnesium casting alloys, Proceedings of 13th International Scientific Conference “Achievements in Mechanical and Materials Engineering” AMME’2005, Gliwice- Wisła, 2005, 199-202.

[7] L.A. Dobrzański, T. Tański, L. Čížek, Influence of heat treatment on structure and mechanical property of the casting magnesium alloys, Proceedings of the International Scientific Conference “Contemporary Achievements in Mechanics, Manufacturing and Materials Science” CAM3S’2005, Gliwice-Zakopane, 2005 (on CD).

[8] W. Liang, et al., Transformation matrix analysis on the shear characteristics in multi-pass ECAP processing and predictive design of new ECAP routes, Materials Science and Engineering 527 (2010) 5557-5564.

[9] W. Penguyue, W. Yucai, X. Shuisheng, H. Guoijie, Numerical simulation on conform process of aluminium alloy rectangular hollow conductor, Materials Science Forum 546-549 (2006) 735-740.

[10] Y. Inwahashi, J. Wang, Z. Horita, M. Nemoto, T.G. Langdon. Principle of equal-channel angular pressing for processing of ultra–fine grained materials, Scripta Materialia 35 (1995) 143- 147.

[11] Y. Beygelzimer, et al., Planar twist extrusion versus twist extrusion, Journal of Materials Processing Technology 211 (2011) 522-529.

[12] A.V. Nagasekhar, et al., Plastic deformation characteristics of cross-equal channel angular pressing, Computational Materials Science 43 (2008) 1069-1073.

[13] V. Varyukhin, Y. Beygelzimer, B. Efros, Nanostructured materials by twist extrusion and high pressure torsion, Materials Science Forum A 584-586 (2008) 102–107.

[14] F.Z. Utyashev, Strain compatibility and nanostructuring of bulk metallic materials via severe plastic deformation, Materials Science Forum 667-669 (2011 45-50.

[15] P.B. Prangnell, C. Harris, S.M. Roberts, Finite element modelling of equal channel angular extrusion, Scripta Materialia 37 (1997) 983-989.

[16] D.P. Delo, S.L. Semiatin, Finite-element modelling of nonisothermal equal-channel angular extrusion, Metallurgical and Materials Transactions A 30 (1999) 1391-1402.

[17] M. Furukawa, Z. Horita, H.G. Langdon, Factors influencing the shearing patterns in equal-channel angular pressing, Materials Science and Engineering A 332 (2002) 97-109.

[18] J.H. Lee, Y.T. Son, Finite element investigation of equal channel angular extrusion process, Materials Transactions, The Japan Institute of Metals 45 (2004) 2165-2171.

[19] T. Ohashi, H. Ito, K. Shinozaki, S. Ito, H. Watari, Analytical and experimental study on lateral extrusion of cross fittings with a lost core, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 399-402.

[20] M. Yu. Gutkin, I.A. Ovidko, C.S. Pande, Theoretical models of plastic deformation processes in nanocrystalline materials, Reviews on Advanced Materials Science 2 (2001) 80-102.

[21] X.D. Zhu, X.J. Xu, Z.H. Zhao, K. Chong, C. Cheng, X.N. Cheng, The novel continuous large deformation technology integrating conventional rolling with equal-channel angular technology, Materials Science Forum 667-669 (2011) 127-132.