

A REVIEW OF MODERN INCREMENTAL METAL-FORMING PROCESSES

GROSMAN Franciszek, TKOCZ Marek

*Silesian University of Technology, Faculty of Materials Engineering and Metallurgy,
Institute of Metals Technology, Katowice, Poland, franciszek.grosman@polsl.pl, marek.tkocz@polsl.pl*

Abstract

Metal forming processes are continually being modified and enhanced in order to obtain products with improved functional properties and to gain new production opportunities and economical benefits. Novel incremental bulk metal forming techniques provide the potential to achieve both these goals. There has been a number of innovative processes developed relatively recently that are based on the incremental forming approach. The paper presents several examples of such processes developed and currently investigated in Polish universities and institutes: KOBO extrusion, forging and rolling aided by additional shear stress, cyclic extrusion-compression as well as forging with a segmented punch. The main features of these forming methods, their benefits and possible application areas have been described.

Keywords: Incremental, forming, SPD, KOBO, CEC, shear stress, strain path, extrusion, forging, rolling

1. INTRODUCTION

A characteristic feature of incremental metal-forming processes is obtaining a required deformation of specific regions in a workpiece through multiple individual deformations caused by pressure (static application of load) or impact (dynamic application of load) of one tooling set within one production stage. There is a number of more or less commonly used processes of this kind, such as some open-die forging operations (e.g. drawing out, spreading, blacksmith forging), swaging, orbital forging, incremental ring rolling, flow forming, etc. [1]. The paper is aimed to present the innovative incremental forming methods, recently developed and tested intensively by Polish scientists. Innovations in these processes consist in modifications of classic metal forming processes through the introduction of additional forces in order to change the stress and strain states in a workpiece and to trigger supplementary material flow. KOBO extrusion and based on the similar principle forging and rolling aided by additional shear stress as well as cyclic extrusion-compression (CEC) represent incremental forming methods that permit to obtain the so called severe plastic deformation (SPD) and in consequence the ultrafine-grained microstructure. The results of various experiments prove that SPD processes significantly expand opportunities to control the microstructure and functional properties of a product in comparison to corresponding conventional processes [2-4]. Some of them, moreover, permit to reduce the press load and the deformation work required to obtain the required effective strain [4,5]. A radical reduction of press load in comparison to equivalent conventional process can be obtained by forging with a segmented punch which is also further shortly described.

The presented incremental forming methods exhibit longer cycle times and require more complex control and machinery than their conventional equivalents. However, they provide a number of benefits which make them an interesting alternative to manufacturing processes of specific product groups. Their main benefits and application potential are collected in a summary.

2. PRINCIPLES OF THE SELECTED INCREMENTAL FORMING PROCESSES

2.1. KOBO extrusion

A principle of the method is to introduce additional deformation of a material through cyclic torsion while it flows out through a die opening. Two variations of this extrusion method have been developed (**Fig. 1**): direct

extrusion (already being applied industrially) and lateral extrusion [6]. A specific, ribbed die is used to conduct the cyclic torsion. Repetitive changes of the strain path cause visco-plastic material flow that enables to obtain very large effective strain in the extruded products in the presence of very advantageous triaxial compressive state of stress [7]. These beneficial features allow for stable performance of the cold extrusion process even for materials considered to be "brittle" under conventional forming (hot extrusion) conditions. Ultra-fine or even nano-crystalline, homogeneous products with improved functional properties can be achieved this way. The process parameters that allow for controlling the strain path and total effective strain to be obtained are: extrusion rate, extrusion ratio and frequency and amplitude of the die torsion angle.

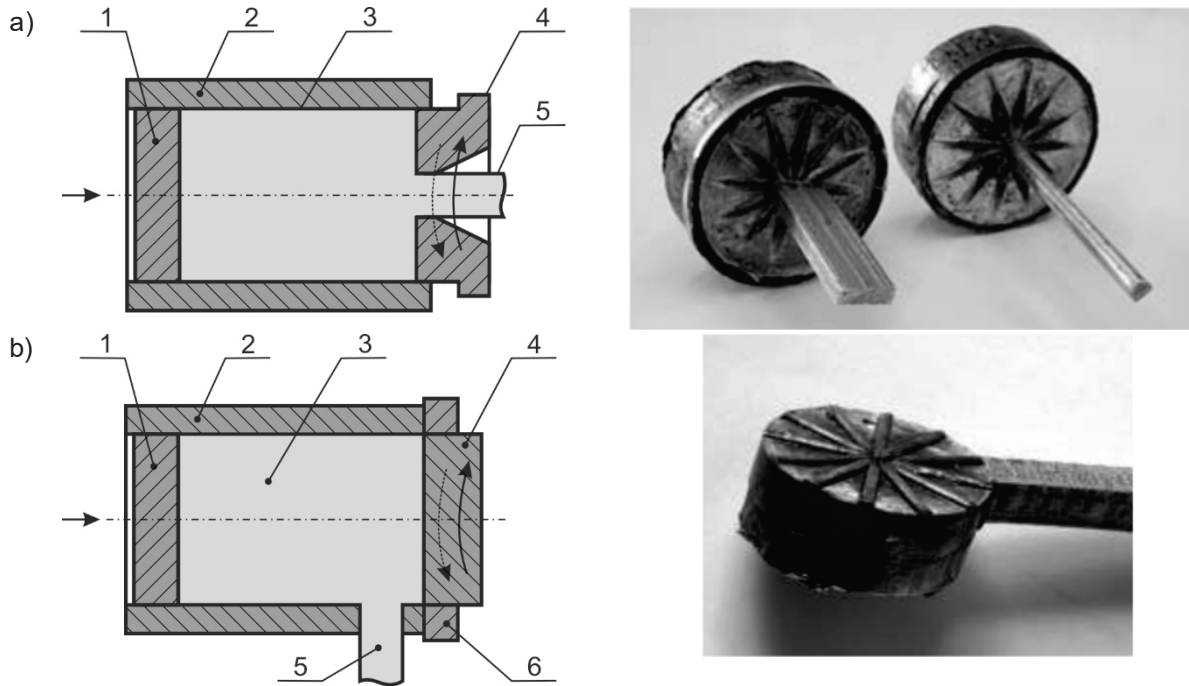


Fig. 1 A schematic representation of KOBODirect extrusion (a) and KOBOLateral extrusion (b) as well as selected extrusions with butts; 1- punch, 2 - container, 3 - billet, 4 - ribbed rotating die, 5 - product, 6 - lock

2.2. Forging aided by additional shear stress

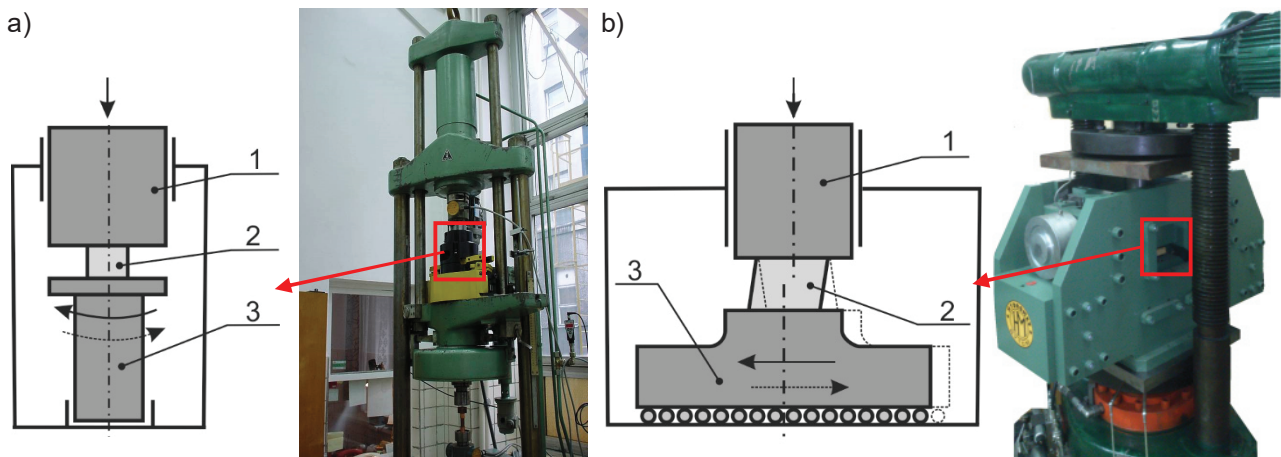


Fig. 2 A schematic representation and photographs of the device for forging with reverse torsion, mounted in the material strength testing machine (a) and the device for forging with transverse motion of a punch, mounted in the working space of a hydraulic press (b): 1 - upper punch, 2 - billet, 3 - lower punch

A principle of this method is similar to KOBO extrusion. Introduction of the oscillatory motion of a punch in the transverse direction to the press load causes additional shear stress in a material. As a result, the significant increase of effective strain can be obtained and lower press load is required in comparison to conventional forging. Two variations of this method have been developed: compression with oscillatory torsion [4,5] and compression with cyclic transverse motion of a punch [8] (**Fig. 2**). Strain path and the total effective strain can be controlled by changing proportions of the process parameters: the compression velocity and the frequency and the amplitude of torsion angle or the frequency and the amplitude of a punch transverse motion, in respect to the method variant.

2.3. Rolling with transverse motion of rolls

The concept presented in previous sections has been adapted also for the rolling process [9,10]. A developed laboratory rolling stand (**Fig. 3**) consists of two rolls, a power unit and a specific eccentricity mechanism to control cyclic motion of both rolls that is transverse to the rolling direction. The mechanism is driven by gear-motor controlled by an inverter, that allows to adjust the frequency of transverse rolls motion. The rolling velocity, the amplitude of rolls transverse motion and the reduction in height can be adjusted as well.

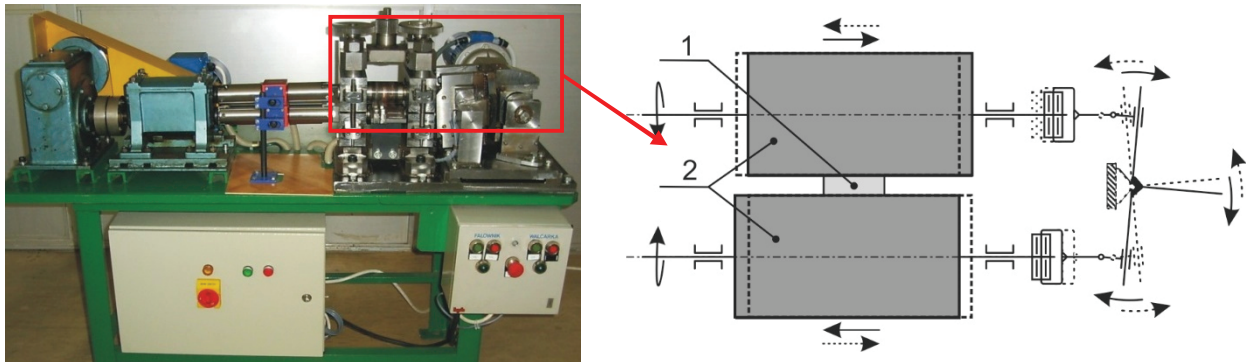


Fig. 3 A photo and a schematic representation of the laboratory rolling mill with transverse motion of rolls:
1 - billet, 2 - rolls

2.4. Cyclic extrusion-compression

Cyclic extrusion-compression (CEC) (named also by the authors as reciprocating extrusion [11]) along with e.g. ECAP method belongs to the group of such SPD (severe plastic deformation) processes that are aimed at radical refinement of the microstructure while the geometric features of a billet remains in fact unchanged. Cyclic deformation is performed by reverse extrusion through a die constriction combined with compression behind the constriction (**Fig. 4**).

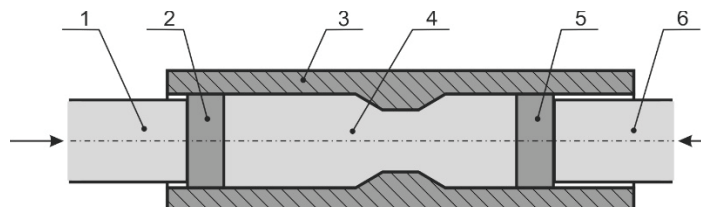


Fig. 4 A schematic representation of cyclic extrusion-compression (CEC);
1,6- rams, 2,5 - dummy blocks, 3 - die, 4 - billet

Two rams are used during every deformation cycle. One of them pushes a billet while the second - located on the opposite side of a die - provides the counter-pressure. By adjusting the counter-pressure, it is possible to control the strain path and the stress state in a billet. The most favorable load pattern is achieved when a material completely fills the space behind the die constriction and the hydrodynamic friction conditions occur.

The effective strain in an individual cycle can be calculated from the ratio of the billet cross-section area to the cross-section area of a die constriction. The total, accumulated effective strain depends on the number of extrusion-compression cycles.

2.5. Forging with segmented punch

This incremental bulk forming method can be defined as a process during which indentations of a relatively large area and a big depth are obtained by accumulation of small indentations made consecutively by individual segments of a relatively small working surface. The concept was initially utilized to develop a device for incremental forging of ribbed round-countoured parts (Fig. 5a) on the orbital press [12,13]. Based on the experience gained during these experiments, a new laboratory device for producing rectangular-contoured panels (Fig. 5b) has been developed [14]. Punch in the device are divided into a number of segments which are collected in several sectors of a punch retainer (Fig. 6). The segments are consecutively pressed by working rolls that move horizontally in the reciprocating manner. Only a few punch segments are pressed against a workpiece at the same time. Hence, it enables to decrease substantially the press load required to execute plastic deformation. The indentation depth in an individual pass depends on a press load applied and the flow stress of a material formed. As the press load is gradually increased in subsequent passes, the segments penetrate deeper and deeper into a workpiece causing a material flow to the gaps between the neighbouring punch sectors and the die walls. A ribbing is formed this way while an advantageous, uninterrupted grain structure is preserved (Fig. 5b). A number and distribution of ribs depends on geometric features of the tooling. Significant reduction of the press load is the most important advantage of the method because the process can be performed even on presses with relatively small maximum press load.

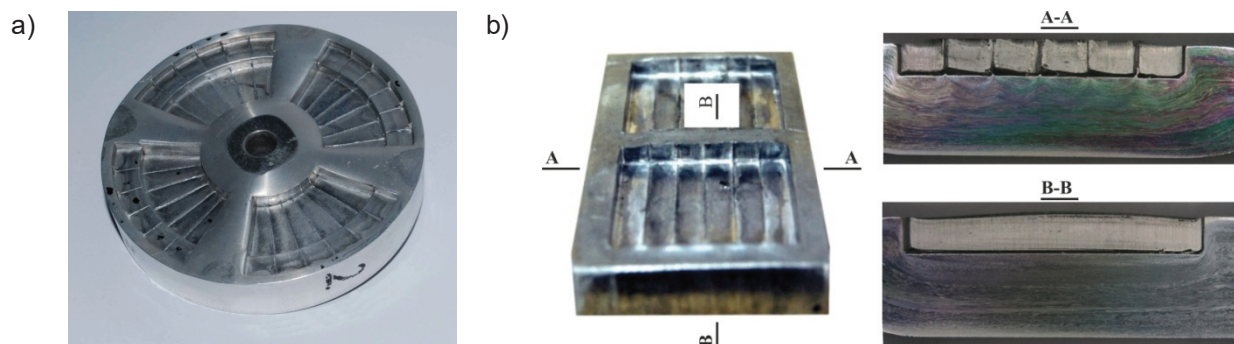


Fig. 5 Round- (a) and rectangular-contoured parts (b) obtained in experimental trials of incremental forging with segmented punch as well as grain structure revealed on the selected sections

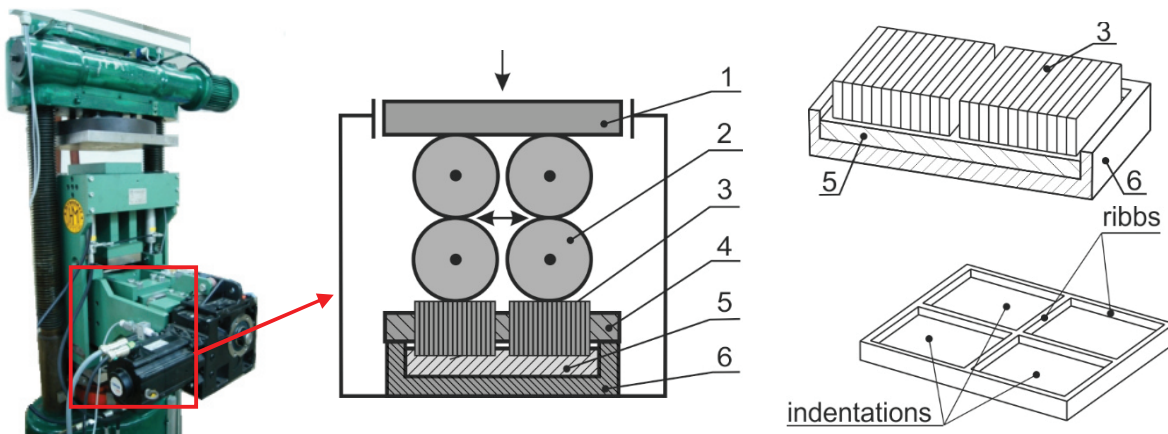


Fig. 6 A schematic representation of the device for incremental forming with segmented punch mounted in the working space of a hydraulic press and typical features of a product; 1 - press punch, 2 - working rolls, 3 - segmented punch, 4 - punch retainer, 5 - billet, 6 - die

3. CONCLUSIONS

The presented bulk incremental forming processes provide a number of important advantages over the equivalent, conventional manufacturing methods. Beneficial deformation of a material is achieved by implementing additional forces that act cyclically on a billet and the effective strain increases in the incremental manner. Thanks to their specific advantages, the methods exhibit a great application potential, especially for the low series production. They can be particularly interested for companies having a limited press load at their command and willing to manufacture products with unconventional set of functional properties.

KOBO extrusion method can be applied to form a number of materials treated as hard-workable or even non-workable in conventional processes, such as composites [15] or magnesium alloys [16]. The method can be also adopted to recycle metal shavings after machining processes [17]. Huge extrusion ratios permit to radically refine the microstructure.

Forging with cyclic, reverse torsion and forging or rolling with reciprocating, transverse motion of dies offer the significant increase of local strains, press load reduction, better die filling [18]. As a result, manufacturing of products with complex shape and the UFG microstructure is possible.

In the CEC process, a shape of the workpiece practically remains unchanged, and the process itself should be treated as a method for manufacturing of UFG stock for subsequent, finishing forming operations. It can be used also, just like the previously mentioned methods, to consolidate porous materials, ie. powders [11], and for eliminating voids in a stock material.

Incremental forming with a set of segmented punches allows for radical press load reduction in comparison to the conventional forging. It provides also the significant materials saving and preserving the uninterrupted grain structure which is not possible after machining. The method is particularly beneficial for manufacturing of the ribbed parts with high surface/thickness ratio e.g. aircraft integral panels [14].

ACKNOWLEDGEMENTS

Financial support of Structural Funds in the Operational Programme - Innovative Economy (IE OP) financed from the European Regional Development Fund - Project "Modern material technologies in aerospace industry", No. POIG.01.01.02-00-015 is gratefully acknowledged

REFERENCES

- [1] GROCHE P., FRITSCHÉ D., TEKKAYA E. A., ALLWOOD J. M., HIRT G., NEUGEBAUER R.: Incremental Bulk Metal Forming, Annals of the CIRP, Vol. 56, No. 2, 2007, pp. 635-656.
- [2] RODAK K., PAWLICKI J., TKOCZ M. Deformation-induced grain refinement in AlMg5 alloy, Solid State Phenom., Vol. 191, 2012, pp. 37-44.
- [3] RODAK K., PAWLICKI J., TKOCZ M. Mechanical and microstructural aspects of severe plastic deformation of austenitic steel, In IOP Conf. Series: Mater. Sci. Eng., Vol. 35, 2012.
- [4] GROSMAN F. New opportunities in the fields of structure forming and decreasing the force parameters in metal forming processes, In MEFORM 2003, Freiberg 26-28.03.2003.
- [5] PAWLICKI J., GROSMAN F. Analysis of power-energy effects for processes with forced deformation path, Archives of Civil and Mechanical Engineering, Vol.4, No.3, 2004, pp. 46-55.
- [6] BOCHNIAK W., KORBEL A., OSTACHOWSKI P., PALIBOREK A. Mechanical properties of aluminum extruded via the KOBO method with direct and lateral outflow, International Journal of Materials Research, Vol. 104, 2013, pp. 974-979.
- [7] KORBEL A., BOCHNIAK W., OSTACHOWSKI P., BŁAŻ L. Visco-plastic flow of metal in dynamic conditions of complex strain scheme, Metallurgical and Materials Transactions A, Vol. 42A, 2011, pp. 2881-2897.
- [8] TKOCZ M., CYGANEK Z., GROSMAN F. The potential and application areas of forging aided by shear stress. Solid State Phenom., Vol. 212, 2014, pp.91-94.

- [9] GROSMAN F., CYGANEK Z. The research of rolling process with cyclic change of the strain path, In Metal Forming Conference 2008, Steel Research International, Special Edition, Vol. 79, 2008, pp. 453-458.
- [10] CYGANEK Z., RODAK K., GROSMAN F. Influence of rolling process with induced strain path on aluminium structure and mechanical properties. Arch. Civ. Mech. Eng. Vol. 13/1, 2013, pp.7-13.
- [11] RICHERT M.W., RICHERT J., HOTŁOŚ A., MROCZKOWSKI M., TOKARSKI T. The effect of reciprocating extrusion (CEC) on the consolidated silver powders microstructure, Archives of Metallurgy and Materials, Vol. 58, 2013, pp.73-75.
- [12] NOWAK J., MADEJ L., PIETRZYK M., GROSMAN F., ZIÓLKIEWICZ S., PLEWIŃSKI A. The incremental forming approach based on the modified classical orbital forging technology, In Materials Science and Technology MS&T'09, October 25-29, 2009, Pittsburgh, Pennsylvania
- [13] NOWAK J., MADEJ L., GROSMAN F., PIETRZYK M. The material flow analysis in the modified orbital forging technology, Materials Science Forum, Vols. 654-656, 2010, pp.1622-1625.
- [14] TKOCZ M., GROSMAN F. Application of incremental metal forming for production of aircraft integral panels. Solid State Phenom., Vol. 212, 2014, pp. 243-246.
- [15] WOŹNIAK J., KOSTECKI M., BRONISZEWSKI K., BOCHNIAK W., OLSZYNA A. Influence of extrusion parameters on SiC distribution and properties of AA6061/SiC composites produced by KOBO method, Journal of International Scientific Publications: Materials, Methods & Technologies, Vol. 7/1, 2013, p. 292-304.
- [16] ZIÓLKIEWICZ S., GAŚIORKIEWICZ M., WESOŁOWSKA P., SZCZEPANIK S., SZYNDLER R. Influence of KOBO treatment on the plastic properties of AM60 magnesium alloy, Obróbka Plastyczna Metali (Metal Forming) Vol. 23/3, 2012, pp. 149-158.
- [17] BOCHNIAK W., KORBEL A. Low temperature consolidation of AZ91 metal shavings, In PLASTMET 2014, Łańcut 25-28.11.2014.
- [18] BOCHNIAK W., KORBEL A., SZYNDLER R., HANARZ R., STALONY-DOBRZAŃSKI F., BŁAŻ L., SNARSKI P. New forging method of bevel gears from structural steel. J. Mater. Process. Technol., Vol. 173, 2006, pp. 75-83.