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DEVELOPMENT OF SPD CONTINUOUS PROCESSES FOR STRIP AND ROD PRODUCTION

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Grain refinement upon the severe plastic deformation (SPD) at low temperatures (below the recrystallization temperature) and an unusual improvement the properties of such materials are shown reliably. However, the industrial application is limited due to the absence of effective continuous SPD processes. The potential of development of continuous SPD processes based on the equal channel angular pressing (ECAP) process from one side and continuous extrusion or drawing processes from another side is considered. Existing various continuous SPD processes for strip, rod and wire production are analyzed.

Key words: severe plastic deformation (SPD), equal – channel angular pressing (ECAP), rod production, strip, wire

Razvitak intenzivnih plastičnih deformacija (IPD) kontinuiranog procesa za trake i šipkaste proizvode. Usitnjavanje zrna pod utjecajem intenzivnih plastičnih deformacija (IPD) na nižim temperaturama (ispod temperature rekristalizacije) i neuobičajno poboljšavanje svojstava takovih materijala se pokazalo stvarnim. Međutim, industrijska primjena je ograničena glede nedostatka efektivnog kontinuiranog procesa IPD. Razmatraju se mogućnosti razvitka kontinuiranog IPD procesa na temelju s jedne strane na kutno kanalnom prešanju (KKP), a s druge strane na kontinuiranoj ekstruziji ili procesu vučenja. Analiziraja se i postojanje različitih kontinuiranih IPD procesa za traku, šipkaste proizvode i žicu.

Ključne riječi: intenzivne plastične deformacije (IPD), kutno kanalno prešanje (KKP), šipkasti proizvodi, traka, žica

INTRODUCTION

The possibility of producing nanocrystalline (grain size smaller than 100 nm) and submicrocrystalline (grain size in the range 100–1000 nm) structures has been reliably established for various severe plastic deformation (SPD) schemes, such as equal-channel angular pressing (ECAP), multiaxial deformation, twist extrusion, high pressure torsion, accumulative roll bonding, and other methods [1-5]. Grain refinement down to a nano- and submicro level results in a significant increase in the strength at satisfactory ductility and to increase the service properties, such as fatigue strength, cold resistance, superplasticity, wear resistance, etc. that is shown already now on various classes of metal materials, including the industrial [1-5]. However, the industrial application is limited due to the absence of effective continuous SPD processes. The potential of development of continuous SPD processes based on the ECAP process from one side and continuous extrusion or drawing processes from another side is considered.

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CONTINUOUS ECAP PROCESSES BASED ON CONTINUOUS PRESSING

Upon conventional pressing, the friction forces acting between the billet and container impede the process. The active friction forces occurring when the billet moves together with the container were used for the development of the continuous pressing methods achieved only due to the friction forces acting between the container and the lateral surface of billet.

Three basic methods of continuous pressing are distinguished: Conform, Linex, and Extrolling. They differ in the mode of the sample input to the deformation zone, i.e., by the nature of the container circulation.

ECAP-Conform process

The Conform method of continuous pressing using the active friction forces was first tested by D. Green in the Laboratory of the Reactor Fuel Cells of the United Kingdom Atomic Energy Authority (Springfield, UK) in 1971 (Figure 1) [6,7].

D. Green proposed a simplest device consisting of a wheel with a ring groove of rectangular cross section at the hoop. The groove with an immobile shoe covering the wheel forms a closed pass. Such design provides a

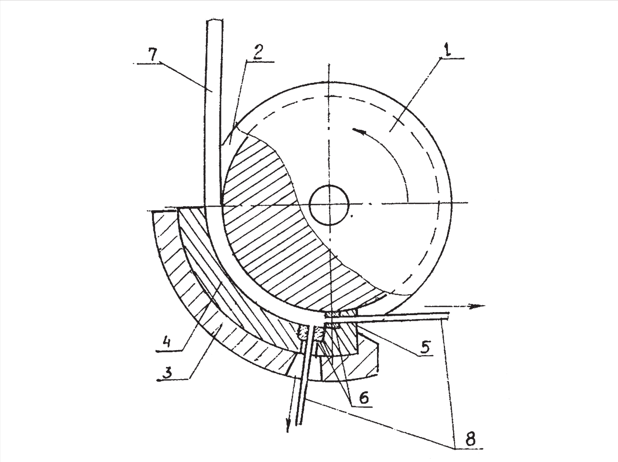

Figure 1 Setup for continuous pressing by the Conform process [6,7]: 1-driving wheel; 2- ring groove; 3- shoe; 4- ring insert; 5- stopper; 6- matrix; 7- semifinished product; 8- finished product

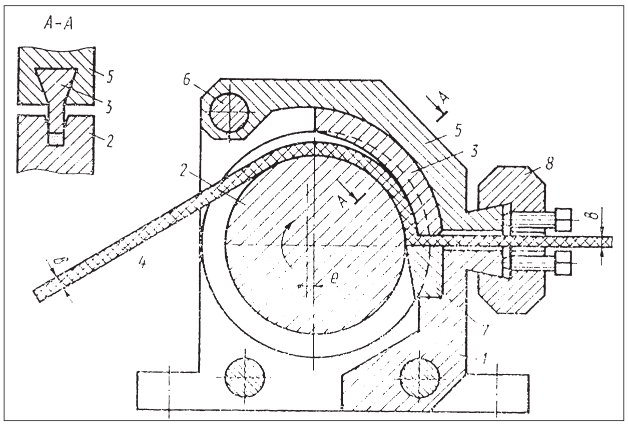

Figure 2 Setup for continuous ECAP of long billets [8,9]: 1- case; 2- square pass drive roll; 3- ring sector insert; 4- semifinished product; 5- jaw; 6- axis of rotation; 7- stopper; 8- wedge clamp

circulation of the pass with three mobile sides belonging to the groove and one immobile side belonging to the shoe. Depending on the matrix arrangement, the devices with radial or tangential metal flow through the matrix calibrating hole are distinguished. There is not reduction of the sample. The samples are moved into the matrix due to friction forces.

V. M. Segal et al proposed continuous simple shear process of long–size rods based on Conform process in 1977 (Figure 2) [8, 9].

This process was successfully realized on copper M1(Russian standart) rods of square section 8 × 8 mm in size [9]. A similar continuous ECAP device was recently made in Ufa, Russia (Figure 3) [10].

The wire from commercially pure Al (99.95 %) of 2,8 × 3,9 × 1000 mm in size was deformed at room temperature with N=4 passes. It was shown that ECAP-Conform process can effectively refine grains and produce ultrafine grained (UFG) structure with average grain size 650 nm [10]. ECAP-Conform process has significantly increased the yield strength (from 47 to 140 MPa) while elongation is decreased (from 28 to 14 %).

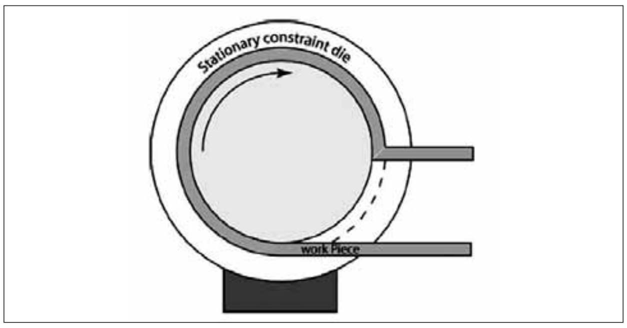

Figure 3 Schematic illustration of the ECAP – Conform setup [10]

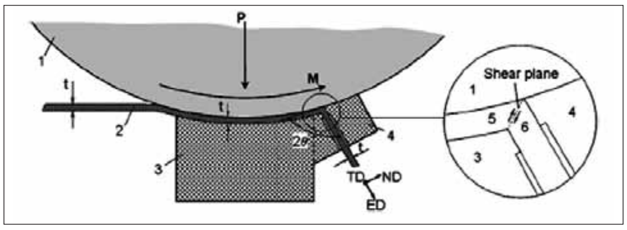

Figure 4 Scheme of the CFAE setup [11]: 1-driving roll; 2- sheet workpiece; 3- workpiece support block; 4 - die assembly, where 2 θ is the extrusion angle; 5- first extrusion channel; 6- second extrusion channel. (ED is the extrusion direction; ND is the normal to the sheet; TD is the transverse direction.)

Recently Y. Huang and P. B. Prangnell [11] designed the Continuous Frictional Angular Extrusion (CFAE) based also on Conform process (Figure 4). They obtained subgrain-grain structure in Al alloy AA1100 with the average size of structural elements ∼ 600 nm.

ECAP-Linex process

The continuous pressing using the Linex method [12-14] is performed by the rectilinear displacement of a plate, which is grabbed from the top and from the bottom by a continuous track assembly (Figure 5). To avoid any metal flow to the sides, immobile sidewalls are provided, which are greased for decreasing friction. Two moving track assemblies and two immobile sidewalls form a closed pass with a matrix installed at the outlet. However, the Linex method is still used rarely. At present, the Conform method is most widely used for the continuous pressing of aluminum alloys.

There is one continuous ECAP process that partially corresponds to the Linex process called Conshering process (Figure 6) [15, 16].

An equal channel angular die is installed at the exit of compact rolling mill called Satellite mill (Figure 6). The process occurs without practically any reduction at room temperature on CP Al AA1100 up to N=6. The size of strip was 2,0 mm in thickness, 19 mm in width and 2000 mm in length. Typical microstructure of cold – worked aluminum having dislocation cells and subgrains is observed after the first or the second pass.

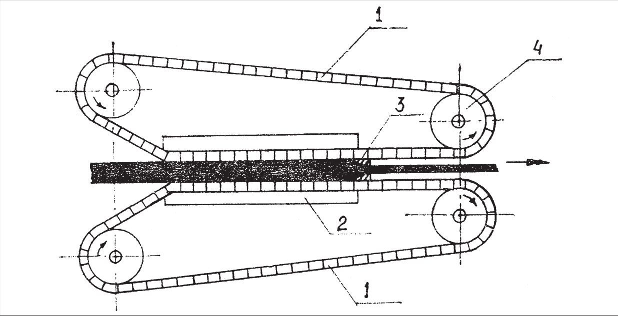

Figure 5 Setup for continuous pressing by the Linex process [12-14]: 1-caterpillar chains; 2- guide member; 3- matrix; 4-cogwheels

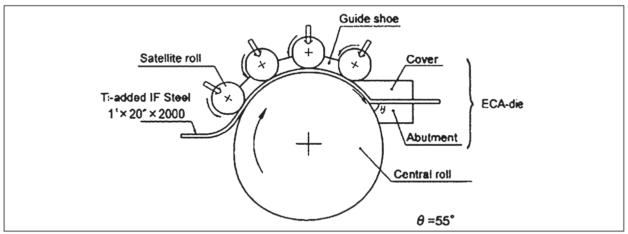

Figure 6 Schematic illustration of the Conshearing process [15,16]

After four passes, it could be observed by approximately 0,5 μm – thick banded structure of subgrains. After six passes, subdivision of the bands to ultra fine grains starts, though the bands remain visible. The mean thickness and the mean length of the grains after six passes are 0,42 μm and 1,44 μm, respectively.

The strength increases with the pass number, except for the excessive angle (70-degree) die. The strengthening is most obvious in the case of the 65-degree die. The tensile strength increases from the initial 100 MPa to 171 MPa by six passes. On the other hand, the elongation to fracture decreases from 50 % to 20 % by one pass operation. However it does not change much after the first pass and still to 23 % after six passes. So the material shows super high strength-ductility balance [16].

ECAP- Extrolling process

The Extrolling process combines rolling and pressing at a stretch [17, 18] (Figure 7). A billet is continuously fed into the pass and deformed in it. By action of rolling forces the billet is pressed out in the expanding section of the pass and squeezed out into the calibrating hole of the matrix installed at the outlet of the pass (Figure 7).

The most well-known and may be single process of continuous ECAP process of strip production bases on Extrolling process is Continuous Confined Strip Shearing (C2S2) (Figure 8) [19].

A specially designed feeding roll and a guide roll with diameter up 10 cm were used as a feeding assembly. The forming die is equipped with two channels. The outlet channel (1,55 mm) is larger then inlet channel (1,45 mm). The strip is reduced into the 1,45 mm thick strip when it is fed through the feeding rolls and when

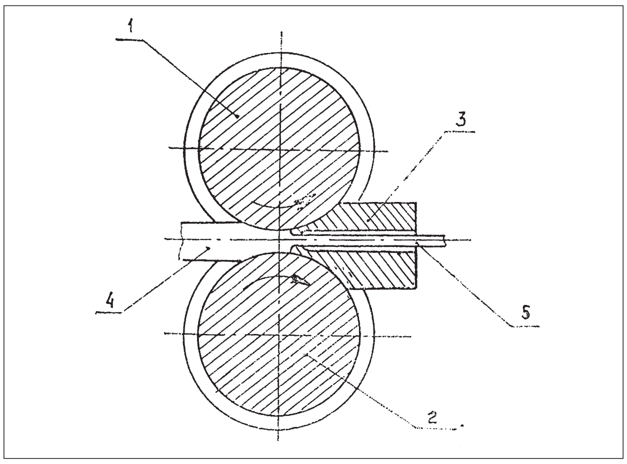

Figure 7 Setup for continuous pressing by the Extrolling process [17,18]: 1-upper roll with groove; 2-bottom roll with groove; 3- matrix; 4- semifinished product; 5- finished product

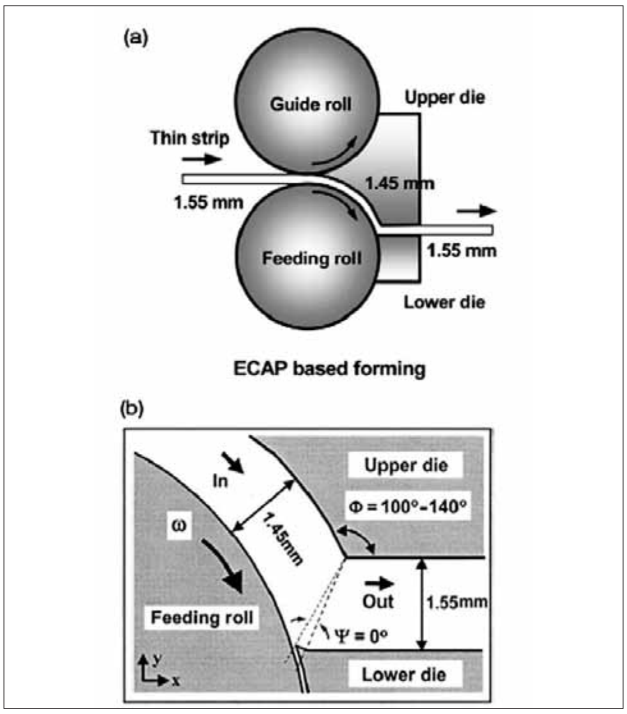

Figure 8 (a) Schematic illustration of C2S2 continuous process based on ECAP for producing the metallic sheets. (b) A detailed die configuration of the forming zone in (a) [19]

the strip exits through the outlet channel, it retains its initial thickness 1,55 mm. This fact makes the multipass operation possible in a continuous manner.

Strips of AA1050 aluminum alloy with dimension of 1,55 × 20 × 1000 mm were fed into the C2S2 machine with different channels intersection angle in range of φ=110-140 ° and deformation cycles up to N=100 (ε=58 at φ=120 °) [19]. After the first pass N=1 dislocation starts tangling to form cell and subgrain structure with high dislocation density inside (Figure 9).

Misorientation angle were measured to be 3-5°. After N=2 the cell size decreased and misorientation increased. At N=5 ultrafine grains with high angle bound-

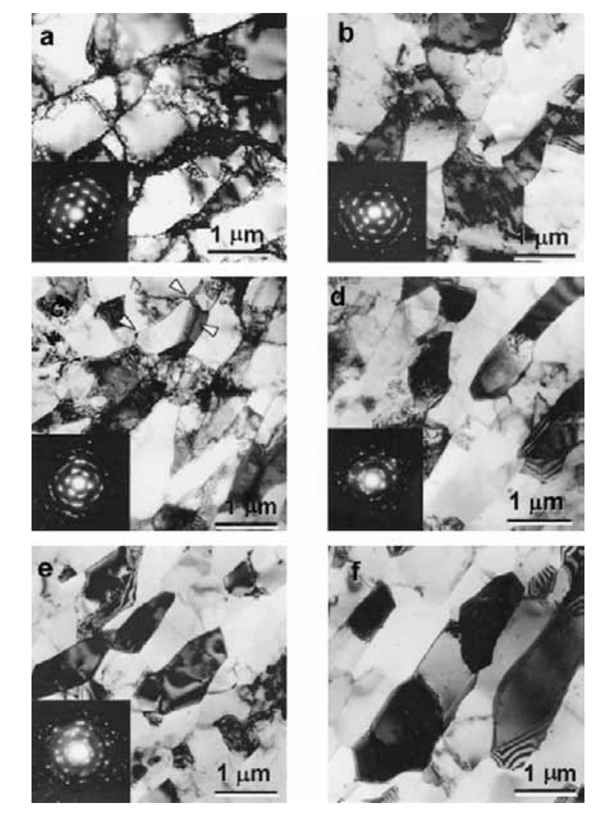

Figure 9 TEM micrographs of Al alloy AA1050 after C2S2 at room temperature at an angle of 120 ° between the channels: (a) N=1(e=0,6), (b) N=2(e=1,2), (c) N=3 (e=1,7), (d) N=5(e=2,9), (e) N=9(e=5,2), and (f) N=50(e=29) [19]

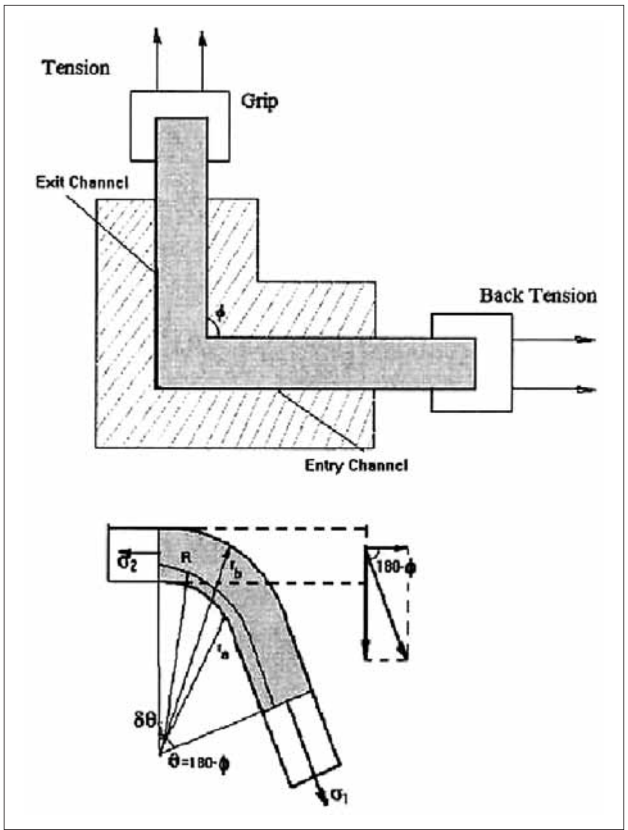

Figure 10 Schematic illustration of drawing through the equal channel angular die [20-22]

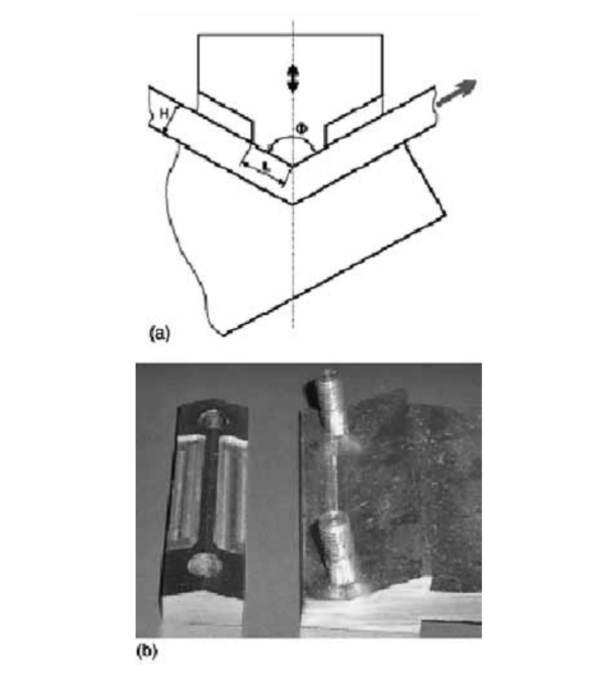

Figure 11 Principal scheme of sheet processing by ECADS (a) and general view of the plunger and the base of the ECADS setup (b) [23]

aries were observed. This structure did not vary significantly with further straining. It should be noted a gradual increase in the grain size with increasing strain.

CONTINUOUS ECAP PROCESSES BASED ON DRAWING

A. B. Suriadi, P. F. Tomson and U. Chakkingal were the first who deformed material by drawing through the equal channel angular die (Figure 10) [20-22]. During Equal Channel Angular Drawing (ECAD) material undergoes a plastic deformation which can be presented as a bending under tension process. Once more ECAD process called Equal Channel Angular Drawing of Sheet Metals (ECADS) was proposed by Dr. Zisman with colleagues [23] (Figure 11). The principal deformation mode was simple shear supplemented by some elongation along the drawing direction and the related thickness reduction. ECADS was used for pure Al at room temperature on a strip of 40 mm in width and 1mm in thickness. The initial yield stress was doubled after four passes, but the deformed structure can be characterized as subgrain dominating structure [23].

CONCLUSIONS

1. Applying continuous SPD processes of strips and rods results mostly in submicrocrystalline structure and materials show high strength- ductility balance.
2. In the present time the methods of SPD continuous processes for strip and rod production are realized and studied rarely. The strip samples in-

vestigated are limited mainly in thickness – 2 mm and in width – 20-30 mm, the rod samples are limited mainly in square section – 10x10 mm.

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Note: The responsible translator for English Language is professor from Baikov Institute of Metallurgy and Materials Science.