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COMBINING THE CASTING AND PUNCHING TECHNOLOGY

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In the article there are presented the results of studying the microstructure of metals obtained by the method of casting and punching in equal-channel step matrixes (ECSM). The analysis of the microstructure of metals obtained on the scanning and transmission microscope showed that owing to realization of intensive shift deformations on the inclined portion of ECSM there emerge shear bands which extend practically in parallel to zones of the matrix channels connection and influence positively closing and sealing all internal defects of cast blanks.

Key words: Al-Si (AL4), deformation, casting, punching, structure.

INTRODUCTION

The main issue facing metal industry today is to improve the quality of metal, such as increasing its mechanical properties, providing a uniform grain structure and other properties that enhance the service life of machine parts, machinery, equipment and other units.

There are many ways of processing metals that enhance the quality of metal products, among them is the equal-channel angular pressing (ECAP) [1]. The feature of this process lies in the fact that by repeating punching the metal through two intersecting channels of equal cross section which are connected with each other at right angles all internal defects located in the connection channels (joint portion) are intensely closed, i.e. metal is subjected to intense shear deformation at junction of channels.

In this case, the measure of forging cast metal (cast metal is exposed to defects) is the intensity of the shear deformation γ, the value of which is determined by the angle of junction of channels of matrix 2 θ, i.e. $\gamma = 2$ ctq θ. With the decreasing of the angle θ, 2 ctq the value of Tincreases, which leads to a significant increasing of the force P, which would require significant expenditure of energy and may cause damage of tools and equipment.

To solve this problem, there is proposed an equal channel step matrix (ECSM) which consists of three equal cross section channels which are connected with each other at the angle $2\ \theta \approx 125^0$ [2]. The metal passing through the channels of the matrix is subjected to the intense deformation in two portions connecting the channels, the total value of which is approximately in the ECAP, but the punching force is greatly reduced because there is no direct obstacle from the walls of the matrix channels.

For example, when pressing in ECAP, the intensity of shear deformation is $\gamma = 2$ ctq $\theta = \gamma = 2$ ctq $45 = 2$, when pressing in ECSM $\gamma = 2$ ctq $62{,}5 * 2 = 2{,}08$, where in the last formula the product by 2 takes into account the number of plots of the channels junction.

However, the ECSM process is characterized by the uneven distribution of stress and deformation over the cross section of blanks, which can be explained as follows: when pressing in ECAP, the end surface of the metal (a and в) is in contact with the wall of the side channel of matrix (Figure 1). Due to the dense contact of metal with the side channel of the matrix, the maxi-

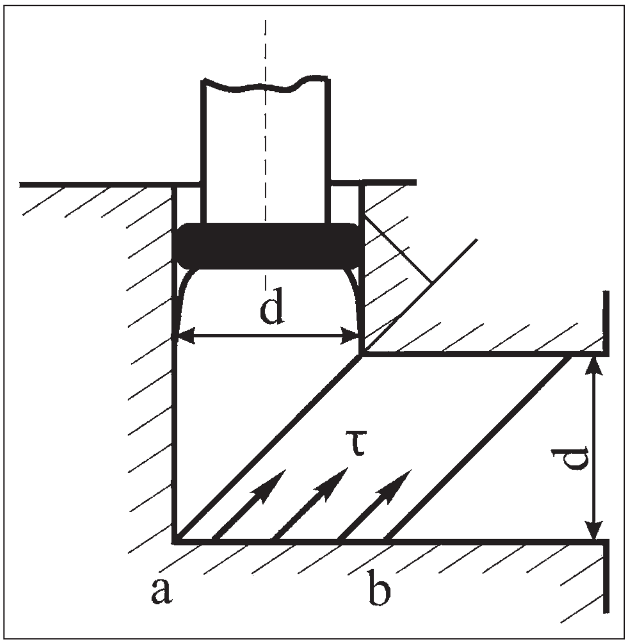

Figure 1 Scheme of equal-channel angular pressing (ECAP); a, b – the surface of contact of the forgings with the wall of the matrix, the τ - the tangential shear stress in the volume of the forgings.

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mum shear stress τ will develop intensely and uniformly, and thus achieves a uniform deformation.

Quite a different picture emerges when pressing in the ECSM, where between the metal end surface and the wall of the intermediate channel there is formed a cavity (Figure 2). Therefore, for the intensification of the maximum shear stress τ it is necessary at first to fill the cavity, which leads to an uneven distribution of deformation over the cross section of the workpiece.

Thus, for intensification of shear stress the end surface is to fit against the walls of thematrix channel. For this it is necessary the use a billet with a curved front end, which cannot be set in the cavity of matrix. Therefore, the only way is to use a casting method to the cavity of the matrix channel followed by pushing through the matrix channels by the metal solidification.

For this there was developed a process of combining casting and punching and the matrix and tooling for its implementation.

Experimental part

To test the effectiveness of the new method of processing metals there was carried out an experiment in the laboratory conditions, i.e. there was implemented the process of combining casting and punching (ECSM) and by solidification of liquid metal (LM) entering through the gate of matrix there will be gradual extrusion of formed casting through the matrix channels of equal cross-section.

The ECSM tools for punching the LM consists of the following main elements: upper punch 1, detachable half matrix 2, with the gating system and half of the cavity of equal channel matrix, lower punch 5, which is the bottom when pouring the LM and outer ring 3, which is half-matrix (Figure 3). Punching being repeated through two intersecting channels of the matrix, metal (casting) will experience large and extra large plastic deformation, which permits the product to get a desired density with improved physical and mechanical properties.

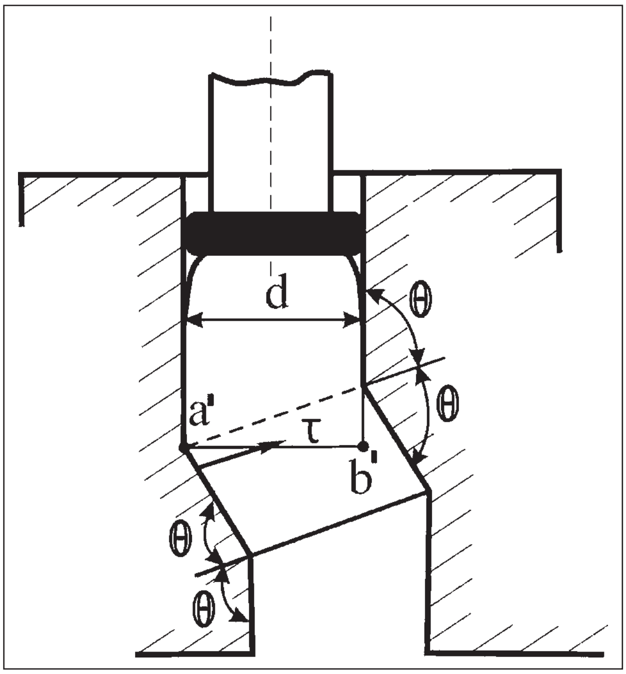


Figure 2 Pressing step in equal channel step matrices (ECSM); d – the diameter of the matrix channel , Θ – the connection angle of channel, a', b' – end surface of the forgings volume, τ - the tangential shear stress in the volume of the forgings

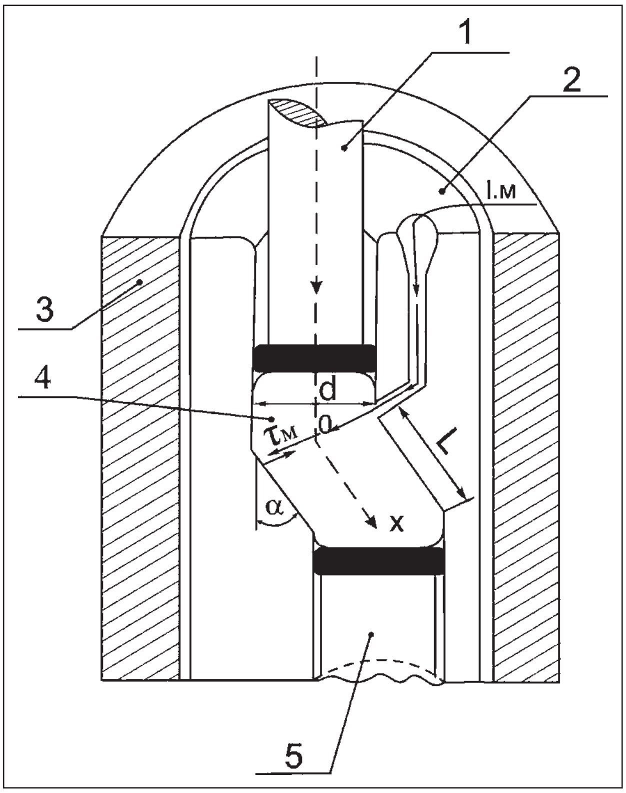


Figure 3 Attachments of the equal channel step matrix. 1- upper punch, 2- half matrix, 3- holder, 4- casting, 5- lower punch

The method of combining casting and punching consists in the following: a certain amount of the LM corresponding to the amount of the obtained casting from themold and intermediate ladles is poured through the gating system directly in the interim and lead-in channels of matrix or is introduced into the cavity of the split matrix consisting of two half-matrix 2. The LM fills the matrix cavity starting from bottom punch 5, which is currently the bottom of the matrix, up to upper punch 1. Thus, the lower matrix is biased and under a small effect of upper punch 1 for casting it does not permit to adhere to the walls of the matrix.

In addition, under the effect of the upper punch shrinkage is accompanied with minimum poring and grinding of the cast structure of metal. The matrix is cooled by water through special openings in the walls of the matrix which are arranged at certain intervals around its circumference. Then, by the metal solidification (crystallization) its punching is started under the impact of upper punch 1 through ECSM channels. Tooling is installed on the lower table of the hydro-pressing installation. Due to the dense arrangement of the solidified casting in the cavity of the matrix channel, in addition to the maximum shear stress τ, which occurs on the stretch of the connection of the matrix channel, there will be increased hydrostatic pressure from the wall matrix. As a result of the simultaneous effect of all inner stresses, the structure of cast metal is worked through intensely and all internal defects are eliminated.

The intense working through is achieved with a reverse cycle of forcing (lower punch 5) after tilting the tooling for 180^0 that is installed on the press table. Due to the fact that the casting in the matrix cavity is established tightly, there is provided a required quality at minimuml punching cycles and energy costs. The outer surface of the half-matrix and the inner surface of the holder are made with a certain inclination to extract easily the casting from the cavity.

Filling the matrix cavity between two punches develops hydrostatic cooling from sides of the matrix walls and the end surfaces of the lower and upper punches, which in turn enables the formation of metal structures with minimal defects of steelmaking. Within the further multicyclic processing under the exposure of upper and lower punches it is necessary to use the heat of the solidifying metal in order to reduce energy costs.

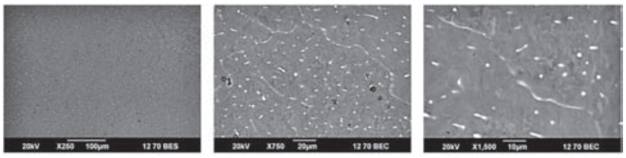
The formation of high-quality metal begins at the step of pouring the molten metal into the die cavity, because shrinkage can be avoided by initial light punching of solidifying casting with liquid core by the upper punch. Therefore, the combination of casting into the matrix cavity and the subsequent bursting will give an opportunity to get better hardware.

Analysis of the experimental study results

This section describes the study of the aluminum samples microstructure (aluminum-silicon alloy Al-Si (AL4), which are obtained by combining casting and punching, The results of the study of the microstructure using a scanning electron microscope (SEM)–EVO-Supra of company Zeiss (Germany) in the reflection mode (chemical contrast) and diffraction of backscattered electron (DBE, bitmap crystal orientation) with the system of microanalyzers of Oxford Instruments company (UK). The microscope resolution was up to 1.2 nm with acceleration 30 kV (secondary electron image), accelerating voltage from 0.5 to 30 kV, magnification from x 10 to x 1 000 000, the current of beam up to 200 nA.

It should be noted that with the help of SEM the image may be obtained fairly quickly, while the diffraction of reflected electrons (CORE) requires long time, up to several hours. Thus, for each sample there were obtained one or two pictures of CORE (diffraction of reflected electrons).

There was used dispersive X-ray spectrometry (DXRS, chemical analysis) of samples. This type of analysis is local (with a sample size of about 1μm 3) and seminumerical (the definition of the elements is contained in the alloy, not their composition).



a) b) c)

Figure 4 Microstructure of a sample of portion II -II (SEM) a) – x 250, b) – x 750, c) – x 1 500

Figure 4 shows the microstructure of the samples, which were cutted from the inclined portion II- II equal channel step matrix (ECSM).

To study the microstructure of the aluminum samples (Al-Si (AL4)) there was used the transmission electron microscope JEM-2100 from JEOL (Japan), in particular for the detection and measurement of the grain boundaries of aluminum samples.

Figure 5 shows the diffraction of reflected electrons (DRE).

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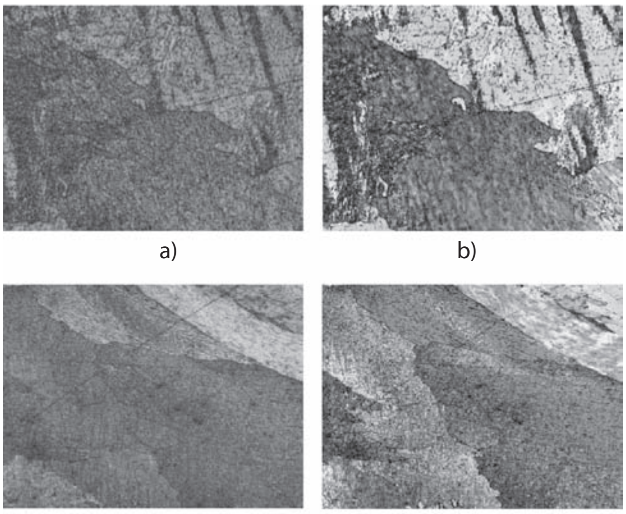
Particular attention was paid to the preparation of samples for transmission electron microscope (TEM). TEM samples should have a thickness less than 500 mkm. High quality of samples is with the thickness which is comparable to the mean free path of electrons in a sample, which can be just a few tens of nanometers.

Materials, having small size in order to be transparent in the electron beam, such as powders or nanotubes, can be easily prepared by applying a tiny amount of material on a supporting mesh or film.

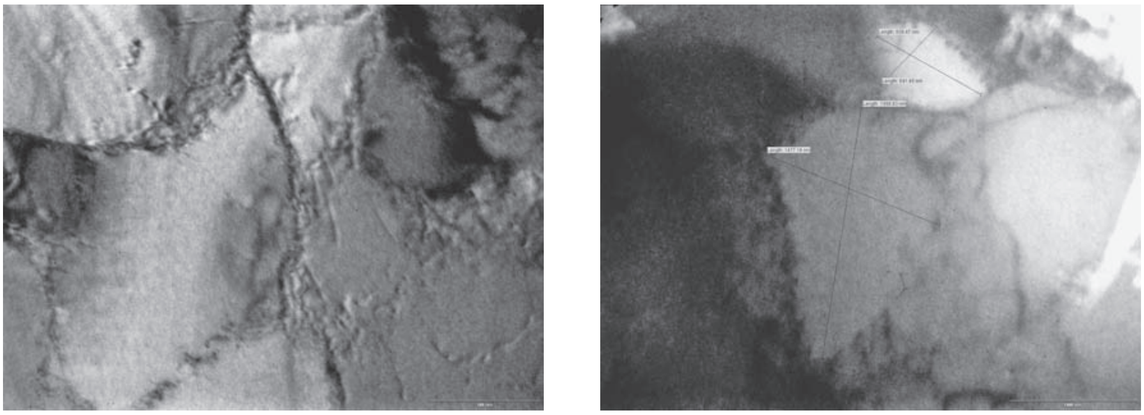
The basic mode in TEM is a bright-field mode. In this mode the contrast is formed by electron scattering and absorption model. The region of the sample with a greater



a) b)

c) d)

Figure 5 Two CORE images of the sample from stretch II- II ECSM with two different magnifications: a) and b) Kikuchi-band image; c) and d) images of crystal orientation



a) 10 000 b) 10 000

Figure 6 Grain boundaries of aluminum sample a) from portion II- II; b) measuring the grain boundaries

thickness and higher atomic number appears darker, whereas the field without a sample in the electron beam is light (so the mode is called bright-field mode).

A part of electrons passing through the crystal sample is dispersed according to the Bragg's law, forming a diffraction contrast. The diffraction contrast is particularly useful in studying the lattice defects.

In Figure 6, a and b there are shown the grain boundaries of aluminum samples with inclined portion II - II. At the same time the grain boundaries are measured at the sample site.

The analysis of the aluminum samples microstructure (AL4) subjected to repeated alternating burst, indicates that on the inclined portion of the matrix II-II there is observed strictly directed metal flow (shear band) or slip lines which extend substantially parallel to portions of the compound of the matrix channel (the joint portion of channels). Orientation of crystals is clearly visible in Figures 4 and 5, where the shear bands are due to the forces that act from the side of the walls of the inclined portion of the matrix. Meanwhile, the analysis of themetals microstructure showed that the microstructure of castings from portions II -II is more equiaxed, as compared with the microstructure obtained on portions I - I (Figure 6 a, b). Furthermore, the microstructure of castings from portions I-I is larger than in portion II-II. Fine grain structure of aluminum workpieces is achieved at three repeating punching cycles, i.e. within the further cycles of punchingthere can be obtained a structure with the grain size of about 200-250 nm.

Although the direction of metal flow is observed, it is more equiaxed due to the fact that the matrix channels have the same cross-sectional area, i.e. no intense stretch of the grain in the direction of the metal flow, as it is observed in direct compression of the metal through the die aperture in the container.

It should be noted that the nature of the metal flow differs from the flow of the metal in direct compression.

On shear bands, which are formed on inclined portion II- II, all internal defects of steelmaking as voids, bubbles, shells, etc. are smoothed and intensely closed.

Shear bands emerge owing to the use of intense shear deformation on inclined portion II – II of the ECSM. Shear deformation concentrates especially on the joint portion of the equal cross-section channels, i.e.in the joint area.

CONCLUSIONS

Thus, with SEM method and the use of PEM there is once again proved the efficiency of the method of casting and punching in ECSM to get high quality hardware.

In the samples subjected to the repeated alternating burst in ECSM there is observed a strictly directed flow of metal (shear bands), it is evidenced by the orientation of the grains.

By cyclic punching in ECSM there can be obtained a uniform fine-grained structure of the metal.

On the shear bands which are formed on inclined portion II- II, all internal defects of steelmaking as voids, bubbles, shells, etc. are smoothed and intensely closed.

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