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RESEARCH PAPER

MECHANICAL PROPERTIES OF PRODUCT FROM 7075 ALUMINUM CHIPS AFTER CONSOLIDATION BY KOBO METHOD

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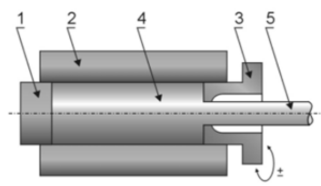
ABSTRACT

This paper presents the possibility of consolidating side products of turning of aluminum alloys into the form and properties of solids metals using low-temperature KoBo extrusion method has been assessed.The proposed method is based on cold compaction of chips into briquettes, and then extrusion by KoBo method at room temperature. The extruded rods were tested for mechanical properties (uniaxial tensile test and Vickers hardness test), and compared with specific mechanical properties of solid material. A very good effect of chips compaction has been proved by KoBo method, which has been confirmed by relatively slightly different mechanical properties of the material after consolidation compared with the solid one.

Keywords: metallic chips, KoBo method, extrusion, mechanical properties of extrudate

INTRODUCTION

Manufacturing metal objects leads to a great amount of scrap material, such as: chips, cuttings or defective components. Most often, such scrap material goes back to steel plants, where it is recycled (by melting) and some part of it can be used again in manufacturing processes.
Aluminum machining chips are one of the most difficult types of scrap to recycle using traditional methods of remelting. It is characterized by elevated surface/volume ratio and it is usually oxidized and covered by different types of contaminants (i.e. lubricants used for the machining process). Due to these features, conventional consolidation by melting technologies may lead to different drawbacks and environmental issues (e.g. fumes and gas formation, energetic/economic issues). In the last years, the consolidation by melting of aluminum alloys has been deeply investigated by many researchers [e.g. 1-5]. From these studies it arises that the recovery rate of the entire process usually hardly reaches 50%. Moreover, the whole process requires several intermediate operations: cleaning, dying, compacting, etc. as well as high energy usage, causing these conventional technologies to be inadequate for the modern industrial needs.
However, there exists another method of metal waste management, which involves its direct conversion into solid material. One of the promising ways of consolidation of metallic scrap, alternative to re-melting, is the technology based on plastic working [e.g. 6-9].
There are great literature reports concerning the consolidation of metallic chips based on the traditional plastic deformation processes (e. g. high-temperature extrusion) [10-22]. However, conventional, high-temperature extrusion of chips does not result in their satisfactory consolidation due to the slight value of extrusion ratio λ and strong surface oxidation of chips. So far, using SPD (Severe Plastic Deformation) in particular ECAP methods to solve this problem, given their low efficiency, have not proved to be very applicable in the industry. That is why, new methods of chip consolidation by low-temperature processes are being investigated. Such a result can be obtained by the use of KoBo extrusion method [e. g. 23-26].
KoBo method is an interesting technical and technological solution allowing for controlling the process of plastic flow of metallic materials, but also an effective method of forming the structure and properties of materials. The application of additional reversible torsion of die by a given angle, at specific frequency (Fig. 1) results in some strain caused by die torsion leading to the existence of viscoplasticity effect of the material [27-31]. The essence of KoBo method is the change of strain path, which leads to the change of stress and results in lower extrusion force.



1 – punch, 2 – container, 3 – reversibly rotating die, 4 – extruded metal/billet, 5- product

Fig. 1 Scheme of extrusion by KoBo method [36]

Superplastic type of metal flow makes it possible to obtain a high quality product, even with complex shapes. As a result, a product is obtained with high plastic properties, suitable for further, direct forming operations [23, 30, 32].
The great advantage of the process compared to classical SPD and extrusion methods is to obtain the product in a single step [30-34], at room temperature and with properly reduced cross sections, even for hardly deformable materials [e.g. 30, 32].
In case of extrusion of chips there are two issues: the necessity of their compaction up to solid state and recreation of joints between individual chips in order to form bulk material/product, which requires inducing a cyclic change of strain path in each of them. In particular, cyclic torsion leads to deformation in the sheared layers, and thus "exposure" of new, non-oxidized surface elements of adjacent chips. High compressive stresses provide them with good mutual adhesion and in effect their stable joint at atomic level [33-35].
The KoBo method is an efficient, low energetic method for consolidation of chips. Each of the five process parameters (temperature, extrusion ratio, extrusion rate, angle and frequency of oscillations) can exert influence on mechanical properties and microstructure. This influence should be considered in order to obtain desirable results.
The aim of the study is to present the possibility of consolidation machining chips from aluminum alloys into products with properties of solids leaving the liquid phase out has been assessed and the analysis of the effects of process parameters on the mechanical properties of the final product. For this purpose, the process of low-temperature extrusion using the KoBo method was used. The proposed method is based on cold compaction of chips into briquettes, and then extrusion by KoBo method without initial heating. The extruded rods were tested for mechanical properties (uniaxial tensile test and Vickers hardness test), and compared with specific mechanical properties of extrudate made of bulk material.

MATERIAL AND METHODS

Experimental procedures

The investigation was conducted on 7075 alloy in the form of chips from manufacturing process and in the form of solid material, for the sake of comparison of the final effects of both methods.

The machining chips coming from the manufacturing processes, contained coolant and lubricant residue. They were not given any cleaning after being produced. In the first stage of the experiment, the chips were compacted. They were put into a special container (cylindrical container with a 60 mm diameter hole) and pressed on a vertical hydraulic press under pressure of 30T. The obtained metal briquettes were used as billets for KoBo method (Fig. 2). The process of consolidation by KoBo extrusion method at low temperature was conducted on the HYDROMET hydraulic KoBo press with the maximum load of 2,5 MN.

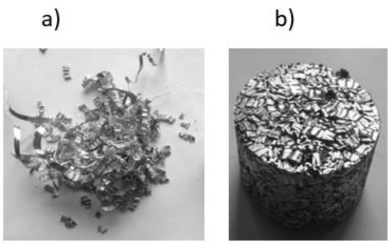


Fig. 2 Chips of 7075 alloys (a) and briquettes (b) made of them as billet for KoBo process

Based on the experimental results obtained in the process of extrusion of solid metals and alloys, the presented experiments were conducted with the amplitude of the die rotation angle equal to ±8°. The frequency of die oscillation was selected in the range of 5÷8Hz. The extrusion process was conducted at room temperature with the use of non-heated briquettes as billets. The extrusion rate was in the range of 0,2-0,25 mm/s .The parameters of the extrusion process were the same for both extruded material (chips and bulk).

As a result of extrusion process ϕ10 mm rod was obtained with the extrusion ratio λ = 36. The obtained products (Fig. 3) were tested for their mechanical properties in a uniaxial tensile test and Vickers hardness test.

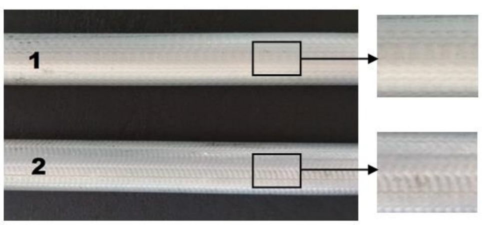


Fig. 3 Rods obtained by KoBo method: 1 – rod made of bulk billet (smooth surface quality), 2 – rod obtained from chips (smooth surface with “pattern” resulting from die rotation)

RESULTS AND DISCUSSION

Investigation of mechanical properties of KoBo extruded rods

Quality evaluation of extrudates is based on the determination of their mechanical properties and surface quality. Test pieces for a static uniaxial tensile test were taken from extruded rods, and test was conducted by means of Zwick/Roell Z100 testing machine. The test pieces were taken from the beginning, middle and end part of the extrudate. They were subjected to tensile test at constant strain rate. Diagrams showing stress–strain (σ – ε) relationship were made, and tensile strength (R_m), yield point ($R_{0,2}$) and elongation (A) were determined.

Also, Vickers hardness tests were taken
according with PN-EN ISO 6507-2 by means of NEXUS 4303 hardness tester. Test pieces for hardness tests were made according with standards mentioned in PN-EN norms (e.g. PN-EN ISO 6507-1:20020. Fig. 4 shows the diagram of tensile tests on rods obtained by consolidation of chips of 7075 in the process of extrusion by Kobo method, whereas Table 1 presents determined mechanical properties.

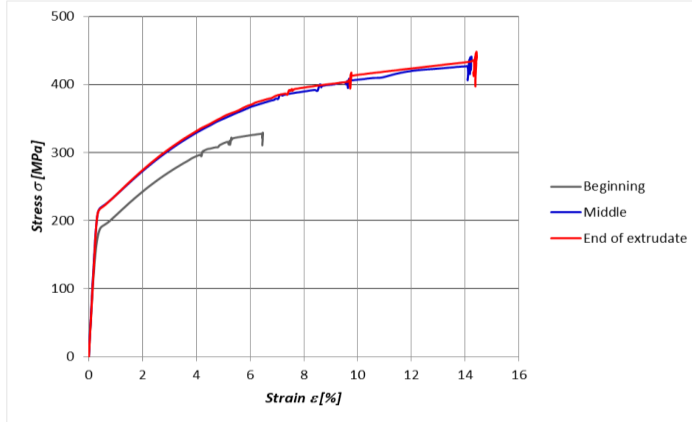


Fig. 4 Tensile curves of ϕ10 mm rods after 7075 chips consolidation by KoBo method

Table 1 Mechanical properties of extrudates made of chips extruded by KoBo method (average values from three test pieces)

Test piece/Properties	R_m [MPa]	$R_{0,2}$ [MPa]	A [%]
7075 – beginning of extrudate	309	190	6.6
7075 – middle of extrudate	385	210	14.2
7075 – end of extrudate	392	219	14.3

By comparing mechanical properties of the material from the extruded consolidated chips in a tensile test, it can be observed that the tensile strength increases as the distance from the beginning of the extrudate grows. The yield point is similar with a significant difference at the end part of the rod. Elongation at specific parts of the rod has shown a considerable growth at the end of the extrudate.

For comparison of the effect of KoBo extrusion of consolidated chips the results of extrusion of bulk material were given. Fig. 5 presents diagrams illustrating tension of rods from bulk material of 7075 alloys in the process of concurrent extrusion by KoBo method, whereas Table 2 shows determined mechanical properties.

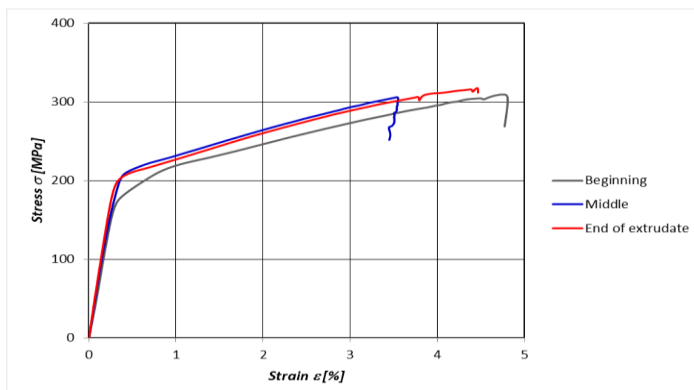


Fig. 5 Tensile curves of ϕ10 mm rods obtained from bulk 7075 materials by KoBo method

Table 2 Mechanical properties of extrudate made of bulk material extruded by KoBo method (average values from three test pieces)

Test piece/Properties	R_m [MPa]	$R_{0,2}$ [MPa]	A [%]
7075 – beginning of extrudate	295	189	4,7
7075 – middle of extrudate	295	214	4,4
7075 – end of extrudate	303	209	3,4

Analyzing the properties of rod made of bulk material of 7075 alloy it can be observed that the tensile strength increases as the distance from the beginning of the extrudate grows. The obtained product is characterized by varied yield point with the lowest point in the beginning part of the tested piece for 7075 alloy. The elongation in the beginning and middle the part of extrudate is considerably different from the yield point measured for the ending part, which proves that the ending part of the extruded rod is relatively brittle. The longer the process, the more flowing the extruded material becomes.
Figure 6 shows the results of Vickers hardness tests with the load of 1N of the sample taken from the middle part of extrudate for 7075 bulk materials and after chips consolidation.

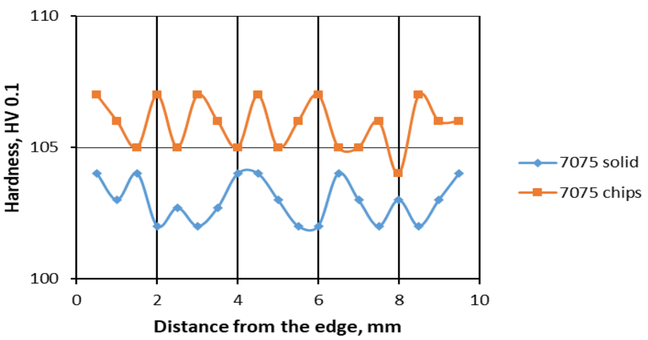


Fig. 6 Hardness distribution in the extrudate made of chips and solid materials by KoBo method

The Vickers hardness tests prove that after chip consolidation by KoBo method the material has better hardness compared with hardness of bulk material made by KoBo method.
The oxide coating after refinement due to plastic strain in the process of extrusion constitutes the hardening phase, which has an advantageous effect on the extrudate's mechanical properties. It is proved by slightly better hardness of aluminum alloy obtained directly after chip consolidation.

Macro- and microstructural observations

The results of microstructural observations of profiles of the extrudate produced by bulk aluminum alloy 7075 during low-temperature KoBo extrusion is presented in fig. 7.

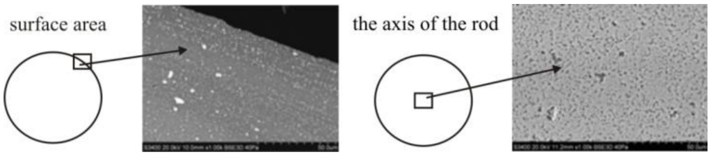


Fig. 7 Microstructures on cross section of rod obtained from bulk 7075 alloy (cut form middle of extrudate)

Based on the observations, in the case of rods extruded from bulk material 7075 the microstructure is highly homogeneous.
In order to determine the type of phases occurring in the alloy, the chemical composition of the precipitates was analyzed in micro-areas and in points by the SEM / EDS method. The tests were carried out on polished surfaces of the digested samples. The microstructure of the 7075 alloy consists of a warp of solid alloys in aluminum and fine precipitates of irregular $MgZn_2$ phase particles and large precipitations of the $FeAl_3$ intermetallic phase, insoluble precipitates $(Fe,Mn)Al_6$ at the grain boundaries and the Mg_2Si dispersion strengthening phase.
In the area of the outside diameter, plastic strain lines are visible, typical for the extrusion process, no cracks, impurities or other discontinuities were found. The plastic forming operations applied did not cause major changes in the morphology of the alloy microstructure components.
The results of microstructural observations of profiles of the compact produced by aluminum alloy 7075 chips consolidation during low-temperature KoBo extrusion are shown in Fig. 8.

Based on the observation of the microstructure of rods extruded from material from consolidated chips, it was found that in the surface areas there are heterogeneities in the form of strongly deformed, elongated bands, without a clear boundary of separation (Fig. 8).

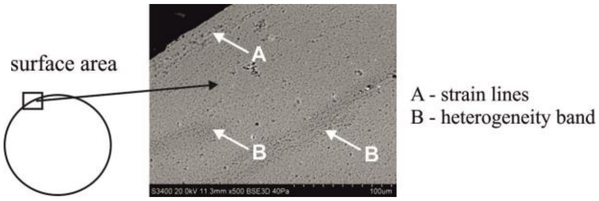


Fig. 8 Microstructures on cross section of extruded rod obtained from 7075 alloy chips

Observations using a larger magnification allowed to state that the bands are areas constituting an integral part of the alloy, not separated by a distinct boundary and differing only in the morphology of the intermetallic phase precipitates.
In addition to the bands of heterogeneity of microstructure related to heterogeneity of alloys in the macroscopic scale, there are also areas in which discontinuities with the appearance of thin boundaries are visible. The analysis of the observation results suggests that they are oxide coating present on the surface of chips that have not degraded in the extrusion process and remained in the alloy representing the shape of the chips. These coatings are fragmentary and make the connection of chips into a fully consolidated material difficult.

CONCLUSION

The investigation of mechanical properties of billets extruded from consolidated chips, compared with the properties of a product extruded from bulk material by KoBo method leads to the following conclusions:
– Low temperaturing extrusion by KoBo method allows for full consolidation of dispersed chips of 7075 aluminum alloy and allows for obtaining long products by cold forming. The presence of impurities in chips, after machining, does not pose a significant difficulty for obtaining a solid product in the process of extrusion by KoBo method.
– The research has shown that the consolidation process of plastic materials based on Al alloys is able to provide very high quality and desired properties of the output product, in some cases even better than for bulk material. Obtaining material possessing good mechanical properties is conditioned by prevention of too thick oxide coatings on the chip particles' surface in the process of refinement and depletion of aluminum oxide coatings on the chip particles' surface as a result of using large plastic deformation.
– The oxide coating after refinement due to plastic strain in the process of extrusion constitutes the hardening phase, which has an advantageous effect on the extrudate's mechanical properties.
– Product made of consolidated chips is characterized by higher strength properties compared with the one obtained from bulk material, at almost twice as high elongation measured in tensile tests (Table 1, 2) and better hardness of aluminum alloy form the extruded consolidated chips (Fig. 6).

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