Similarities between the Serrated Chips in High Speed Turning and the Defected Work Piece of ZA22 after Pressing by the Equal Channel Angular Pressing, ECAP

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Abstract— Severe plastic deformation processes are relatively recent manufacturing processes used for producing fine grain structure in metals and their alloys. The equal channel angular pressing is the mostly used process among them. During the use of this process on zinc 22% aluminum alloy grain refined by molybdenum in the mechanically dry condition, i.e. without lubrication, the pressed work piece was segmented on its interface in contact the ECAP die; similar to the serrated chip observed in turning of low Ernst and Merchant in 1940 and recently observed in high speed turning of stainless steel and other metallic alloys at high values of feed rate and depths of cut. In this paper, the mechanism of formation of the ZA22 in the ECAP process and the serrated chips in the high speed turning of stainless steel and other material is presented and discussed. Furthermore, it was found that the number of segments and the distance between them, (the pitch) was varied depending on the chemical composition of the work piece material. Also the causes of this new phenomenon, the mechanism of its formation and how to avoid its occurrence are also presented and discussed. Finally, the segmented specimens were sectioned, projected, magnified and presented in the paper. The presented work in this paper is expected to be of value not only to the development of the ECAP process but also in the high speed turning process and also of special importance to grinding and polishing processes which results in further enhancement of the surface quality.

Index Terms— Similarities, Serrated chips, High speed turning, Low thermal conductivity, Segmented ZA22 work piece, Equal channel angular pressing, ECAP.

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1 INTRODUCTION

Researchers are always working for continued improvement in the quality of the manufactured products, as produced by the various forming and machining methods. Since the development of the zinc alloys, ZA, with higher aluminum contents; they are increasing in demand for manufacturing many parts for the automobile, aircraft and space craft industries for their required and attractive properties, [1-3]. These new zinc–aluminum based alloys have high strength and hardness, improved creep and wear resistances and have lower density. Although they were originally developed for sand and gravity casting, they are now being used in growing amounts for pressure die casting, [5]. Also they are ideal for manufacturing parts which require to be machined, pressed, stamped and fabricated items including mobile phone antennae, portable computers, disk drives, radio frequency circuits, transformer cores, heat sinks, shutter mechanisms in cameras, and many other electrical and electronics consumer applications, [4]. ZA22, is one of the most common alloys in ZA series, where at this composition a eutectoid transformation occurs which exhibits a superplastic behavior at temperature of 275°C [6], which makes it suitable for manufacturing deep-drawn products. However, against these attractive properties they have the disadvantage of forming a dendritic structure with large grain size during solidification or homogenization of their casts, which tends to reduce their surface quality, mechanical and impact strengths. Hence it became a necessity to modify their structure and refine their grains. Normally, they are grain refined by:

i) Addition of some rare earth elements e.g. titanium and titanium+boron. The literature on this method is voluminous and has been reviewed by the author for aluminum and its alloys in Ref. [4] and for zinc aluminum alloys in Ref. [7]. Recently. The different methods for grain refinement of materials are reported in Ref. [8].

ii) By subjecting the material to severe plastic deformation, SPD, e.g. rolling and re-rolling, extrusion with high extrusion ratio…etc.

A new method was suggested, applied and published by the author in Ref. [9]. In this paper, the effect of addition of Mo to ZAl22, ZA22 grain refined by Ti and Ti-B as grain refiners and subjecting it to severe plastic deformation by the equal channel angular pressing, ECAP is presented and the obtained results are discussed. Furthermore, the formation of the defected of the work pieces which were segmented after the pressing process together with the similarities between their formation and the formation of the surface roughness of machined surfaces in metal cutting processes which were first reported by Ernst and Merchant in 1940, [10] and recently in the formation of serrated chips in urning of materials at high speeds, high feed rates and large depths of cut are also presented and discussed. To the best of the author knowledge the available literature reveals that no papers (except the author paper, Ref. [9]), there does not seem to be any other publica-

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tion which combines the two methods together. This formed the main objective of this paper.

2 MATERIALS AND EXPERIMENTAL PROCEDURE

2.1 Materials

Throughout this work, different materials, namely: pure granular zinc and commercially pure aluminum of the chemical compositions shown in tables 1 and 2, respectively, were used in manufacturing the zinc- 22% aluminum, ZA22, main alloy. High purity molybdenum, titanium and aluminum were used in manufacturing the following binary master alloys: Al- Mo and Al-Ti. The ternary master alloy Al-Ti-B was commercially available and was supplied by the Arab Company for manufacturing aluminum. These three master alloys were used as grain refiners for the ZA22 main alloy and for the manufacturing of its different micro alloys. Pure graphite crucibles were used in manufacturing the main alloy ZA22, master alloys and the different ZA22 micro-alloys, and pure graphite rods were used for stirring purposes.

TABLE 1
CHEMICAL COMPOSITION OF GRANULAR ZINC

Element	Wt %
Pb	0.003
Fe	0.002
Cu	0.004
Al	0.005
Sn	0.002
Cd	0.002
Zn	Bal

TABLE 2
THE CHEMICAL COMPOSITION OF ALUMINUM

Element	Wt %
Fe	0.09
Si	0.05
Cu	0.005
Mg	0.004
Ti	0.004
V	0.008
Zn	0.005
Mn	0.001
Na	0.005
Al	Bal.

The commercially pure aluminum was obtained from Jordan Electricity Authority in the form of bundles of wires. They were cut into small pieces and pickled by immersing them in (95% Distilled water and 5% concentrated HCl) up to five hours to get rid of the oxide layer and other contaminants.

Three master alloys were used to obtain the different micro alloys two binary alloys. The ternary Al 4.99%Ti-0.99%B was commercially available. It was obtained from ARAL (Arab Aluminum factory in Amman) in the form of rod 10 mm diameter. Its chemical composition is shown in table 3.

Pure graphite crucibles were used in manufacturing the main alloy ZA22, master alloys and the different ZA22 microalloys, and pure graphite rods were used for stirring purposes. The commercially pure aluminum was obtained from Jordan Electricity Authority in the form of bundles of wires. They were cut into small pieces and pickled by immersing them in 95% distilled water and 5% concentrated HCl to get rid of the oxide layer and other contaminants.

2.2 MASTER ALLOYS

Two binary master alloys Al-10.4% Ti and Al-7.4% were prepared from high purity metals to obtain the different micro alloys. which were later used for manufacturing of the different ZA22 microalloys. The ternary Al-5%Ti-1%B was commercially available and obtained from Arab Aluminum Co. (ARAL) which produces sections and products made of aluminum. Their chemical compositions as determined by the scanning electron microscope, SEM. The equal channel angular pressing tests were carried out using the designed and manufactured die shown in Fig.1. It was made of die steel H13 of the chemical composition shown in table 4.

TABLE 3
CHEMICAL COMPOSITION OF AL-4.9%TI-0.99%B TERNARY MASTER ALLOY, WT % .

Element	Wt %
Ti	4.9
B	0.99
Fe	0.12
Si	0.09
V	0.12
AL	Bal.
GrainSize,(µm)	179

Heat treated H13 tool steel of the composition shown in table 4 was used in manufacturing the Equal Channel Angular Pressing, ECAP, die.

TABLE 4
CHEMICAL COMPOSITION OF TOOL STEEL H13

Element	Wt%
C	0.45
Si	0.8
Cr	5.5
Ni	0.3
Mo	1.7
Cu	0.25
V	1.2
Mn	0.2
Fe	Reminder

TABLE 5
CHEMICAL COMPOSITION OF THE DIFFERENT ZA22 MICROALLOYS

No	Alloys	Mo%	Ti%	B%	Al%	Zn%
1	ZA	0	0	0	21.91	Bal
2	ZA-Mo	0.094	0	0	21.98	Bal
3	ZA-Ti	0.15	0	0	21.97	Bal
4	ZA-Ti-Mo	0.094	0.141	0	1.95	Bal
5	ZA-Ti-B	0	0.048	0.0096	21.99	Bal
6	ZA-Ti-B-Mo	0.047	0.047	0.0093	21.96	Bal

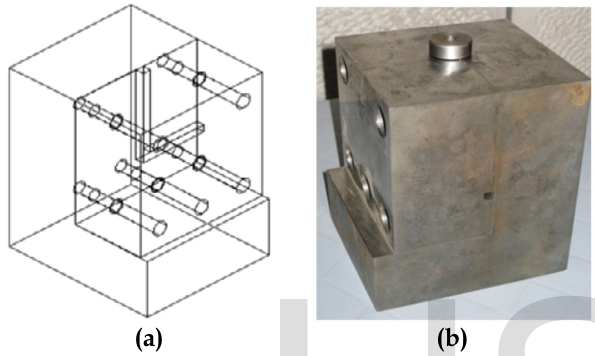
(a) (b)

Fig. 1. a) Schematic drawing of the ECAP die, and b) Photograph of the ECAP die.

3 EXPERIMENTAL PROCEDURES

The experimental procedure started by melting the predetermined amounts of aluminum and copper in a graphite crucible inside an electric resistance furnace of 1200 degrees C. After melting the mixture is poured to solidify and cool to room temperature in thick hollow steel dies of 40 mm thick-ness having an internal cross section of 160 mm length and 45 mm width and 6 mm depth.

The experimental procedure started by preparing the master alloys from which the different micro alloys were pre-pared; followed by preparing the specimens for the micro-structure examination, hardness measurement and mechanical behavior. Then the Vickers micro hardness, (HV), of each specimen was determined in the cast and after ECAP pressing, using the digital micro hardness tester (model HWDM-3). Ten readings were taken on the surface of each specimen from which the average HV micro hardness was determined. The mechanical behaviors of the ZA22 and its different microalloys were determined from their corresponding load - deflections curves, (autographic records), which were obtained from compression tests on cylindrical specimens of 10 mm diameter and 10 mm height on an Instrun Universal testing machine of 250 KN capacity.

4 RESULTS AND DISCUSSION

To understand the mechanism of deformation it was necessary to study the microstructure of the different microalloys, Fig.1, their grain size, Fig.2 and table 6, hardness of the base alloy, ZA22, and its different microalloys: ZA22-Mo, ZA22-TiB, ZA22-Ti in the cast condition and after the ECAP process, Fig.3 and the mechanical characteristics of ZA22 and its different micro alloys before and after ECAP process in tables 7 and 8, respectively.

4.1 Effect of the Addition on the Grain Size of ZA22

It can be seen from Fig.2 and table 6 that addition of any of the elements Mo, Ti-B or Ti to ZA22 resulted in reducing its grain size by the following percentages: 30.45%, 45.84% and 40.28% in case of Ti-B, Ti and Mo, respectively, which illustrates that the presence of boron activates the refining efficiency of Ti although boron is not a refiner if added alone. This agrees with previous findings, Refs. [8,9].

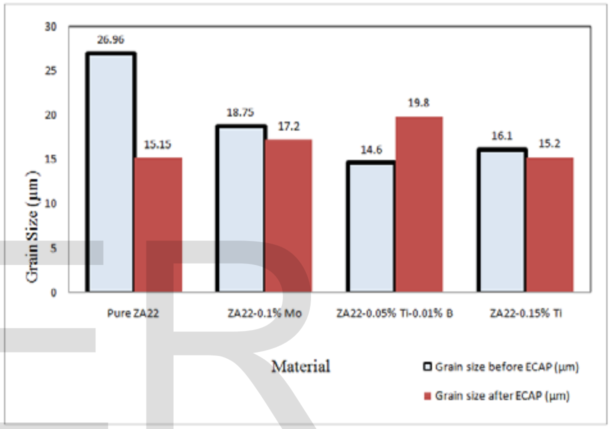

Fig. 2. Grain size of ZA22 and its different micro alloys before and after ECAP process.

TABLE 6
GRAIN SIZE OF ZA22 GRAIN REFINED BY MO, TI, AND TI-B IN BOTH BEFORE AND AFTER ECAP

Alloy	Grain size (µm Before ECAP	Grain size (µm) After ECAP	Reduction Rate %
Pure ZA22	26.96	15.15	43.81
ZA22-0.1% Mo	18.75	17.2	8.27
ZA22-0.05% Ti-0.01% B	14.6	19.8	-35.62
ZA22-0.15% Ti	16.1	15.2	5.59

4.2 Effect of the addition on the micro hardness of ZA22 and its different micro alloys

It can be seen from Fig. 3 that the effect of addition of any of the elements Mo, Ti-B or Ti to ZA22 resulted in reduction of its hardness by 7.83%, 14.67% and 15.85%, respectively. The ECAP process resulted in further decrease of the alloy hardness with the following rates: 24.23%, 48.72%, 57.52% and 55.9% in ZA22, ZA22-Mo, ZA22-Ti-B and ZA22-Ti respectively.

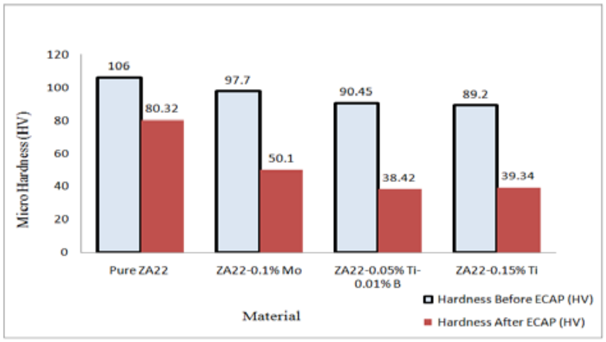

Fig. 3. Micro hardness of ZA22 and its different micro alloys before and after ECAP.

4.3 Effect of the addition on the mechanical characteristics of ZA22 and its different micro alloys

Summary of the mechanical characteristics of ZA22 and its micro alloys in cast and after ECAP conditions are given in tables 7 and 8, respectively; from which it can be seen that in the cast condition, there is hardly any variation in the strength coefficient less than 0.2% decrease and a decrease of 13% in case of Ti-B addition but the strength coefficient was slightly increased by 1.92%. Regarding the strain hardening index it can be seen that it has a minus value by the addition of any of the refiners which indicates that softening has occurred. The maximum decrease was in case of Ti-B addition. This gave the indication that superplastic behavior might have taken place in the microalloys at different rates and the maximum is in case of Ti-B addition. This is logical due to the decrease in hardness and the grain size. To prove this tensile tests are now carried out by a postgraduate student to find out the amount of elongation percentage both in the cast and after ECAP process as the same trend is observed in table 8.

TABLE 7
MECHANICAL CHARACTERISTICS OF ZA22 AND ITS DIFFERENT MICRO ALLOYS AS CAST

No	Alloy	Strain hardening index (n)	Strength coefficient (k) Mpa	Mechanical behavic equation in plastic region MPa
1	Pure ZA22	0.0225	286.49	$\sigma = 286.49\ Є^{-0.0225}$
2	ZA22-0.1% Mo	0.1049	249.14	$\sigma = 249.14\ Є^{-0.1049}$
3	ZA22-0.15% Ti	0.077	291.98	$\sigma = 291.98\ Є^{-0.077}$
4	ZA22-0.05% Ti-0.01% B	0.0763	285.92	$\sigma = 285.92\ Є^{-0.0763}$

TABLE 8
THE MECHANICAL CHARACTERISTICS OF ZA22 AND ITS MICROALLOYS AFTER ECAP

No	Alloy	Strain hardening index (n)	Strength coefficient (k) Mpa	Mechanical behavior equation in plastic region MPa
1	Pure ZA22	0.0708	232.29	$\sigma = 232.29\ Є^{0.0708}$
2	ZA22-0.1% Mo	0.0456	205.96	$\sigma = 205.96\ Є^{0.0456}$
3	ZA22-0.15% Ti	0.0569	210.31	$\sigma = 210.31\ Є^{-0.0569}$
4	ZA22-0.05% Ti-0.01% B	0.0667	181.36	$\sigma = 181.36\ Є^{0.0667}$

4.4 Mechanism of deformation

Consider two mating mechanically clean surfaces are in contact and subjected to sliding force. At the beginning, the resistance to shear is low at their actual areas of contact i.e. at the peaks and the resistance to shear is low. As the process of forming or cutting continues the area of contact between the two mating surfaces increases which gives rise to very high levels of friction which leads to shearing of the metal surface of the work piece being of lower strength and hardness than the ECAP die during the pressing process or the cutting tool respectively. It may be concluded from these principles that friction between the parts in contact and the shear strength of the work piece are the most important parameters which are responsible for the segments formation in the ECAP work pieces and the serrated chips in the turning operation on low thermal conductivity materials like titanium and its alloys. This paper presents a further step in this development, and sets forth a new concept for the limitations of the process. It reveals the fact that an extremely high values of friction between the work piece and the die walls during the severe shearing process may lead to tearing of the outer surface of the work piece into segments, similar in shape to the serrated type of chip which is formed in orthogonal cutting of low thermal conductivity materials and in very high speed turning at large depth of cut and high feed rate when the built up edge is sheared off, after being formed, with the continuation of the cutting process. The segmented flow of ZA22 and its micro alloys were magnified 10 times and shown in Figs. 4 (a), (b), (c), (d), and (e).

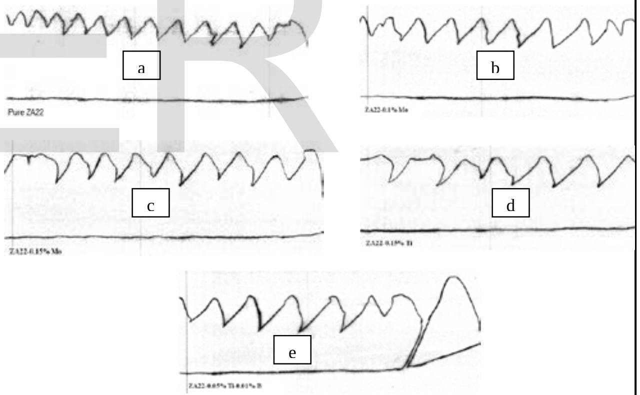

Fig. 4. The segmented work pieces of ZA22 and its microalloys.

This behavior is similar to the segmented or non-homogenous chip in orthogonal cutting of metals possessing low thermal conductivity. Similarly, this saw teeth behavior may occur in shear zone of low and high shear strain which exists in the work pieces of ZA22 and its microalloys in the ECAP process as the mechanical strength decreases due to adiabatic temperature rise in the region in contact with the die. Non-homogenous or serrated chip was reported during turning of stainless steel (SA321) at 0.2 mm depth of cut and 1.2 m/sec speed, Ref. [2], and in high speed turning of Al-Ti alloy, Fig.5.

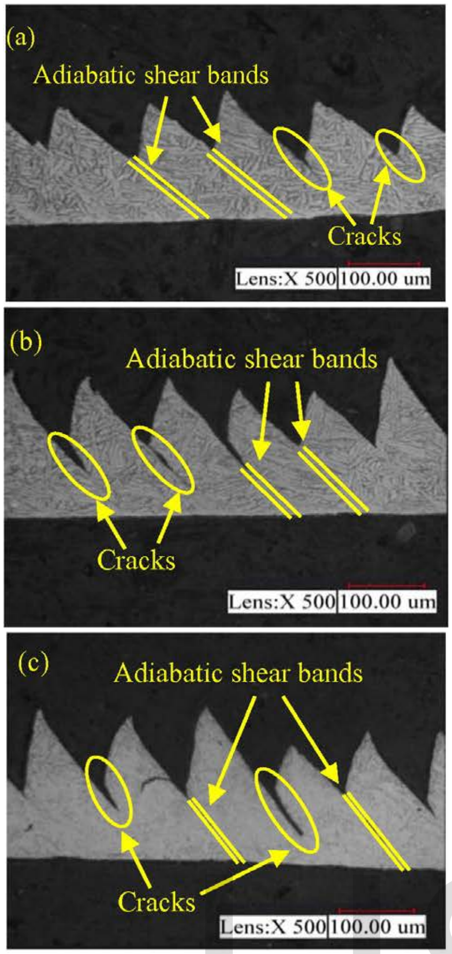

Fig. 5. Non-homogenous segmented or serrated chip from turning of Al-Ti alloy.

5 CONCLUSIONS

From the previous discussion the similarity between the formation of the segmented work pieces of the ZA22 and the serrated chips in metal cutting processes is clear. Furthermore, it is apparent that great advance in the ECAP field may yet be made especially if effective and efficient lubricants can be developed which will provide and maintain low friction at the interface, (the contact area between the work piece and the die) which will result in low shear force at the interface. Investigation of different types of heavy oils, semi-sold and solid lubricants is in progress and the preliminary results are promising.

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