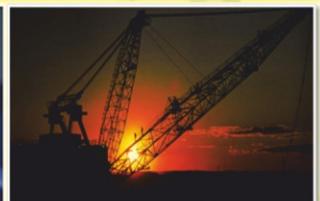


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Influence of Accumulative back Extrusion and Lubricants on the Hardness of Al 6063 Alloy

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A B S T R A C T

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The current accumulative back extrusion (ABE), a severe plastic deformation (SPD) process, is intended to improve hardness of commercially available Al 6063 alloy without compromising its ductility after undergoing plastic deformation. The novel technique consists of three innovative punch setup design to act sequentially. The first punch, smaller than the billet, pierce through with excess material flowing backward forming a cup shape, this is followed by the second punch, which is hollow, pushing the cup flanged back and thereby pushing the inner punch backward, extruding a rod. The final stage of pushing the whole billet back to the initial size and shape is achieved by the third punch which has the same diameter as the billet. This technique (ABE) was applied to a commercially aluminum specimen AA6063 to see the possible degree of improvement. It was discovered that the hardness of AA6063 was increased from 15HRE to 26HRE during cup extrusion and to 37HRE after the final stage of rod extrusion in a single operation. The whole cycle can be repeated to achieve higher hardness and improve mechanical properties.

1. Introduction

Severe plastic deformation processes can be defined as those processes that induce very high plastic strain in a metal in order to cause grain refinement. The equal-channel angular extrusion/pressing (ECAE/P) process was developed in Russia during the 1970s (Segal 1977; Segal, et al. 1981) as a method for introducing large plastic strains in a metal, while maintaining the outer dimensions of the work piece substantially unchanged. Though such processes have been known for many decades, there has been a recent upsurge in a new class of SPD processes which generally have one characteristic feature, namely the size and shape of the work-piece remains unchanged after SPD processing. The new SPD processes, such as equal channel angular extrusion or pressing (ECAE/P), high pressure torsion (HPT), accumulative roll bonding (ARB) and multi-axial compression/forging (MAC/F) all aim to keep the starting and finishing work piece shapes the same. ECAE/P, is discussed below, followed by some of the other processes. Among the processes discussed some like ECAE/P, MAC/F, and HPT introduce severe plastic deformation on bulk materials, while others like ARB, RCS, and Con-shear work on sheet materials. In all these techniques, a very large amount of de-formation is achieved without any shape change.

However, the large friction between the workpiece and the tools is considered as the primary drawbacks of the ECAE/P process in which most material currently produced consist only of small cross-

sections and short lengths for laboratory studies. Equally, there is a substantial amount of undeformed material at the leading and trailing end of each piece. Segal et al. (1995) and Semiatin et al. (1999) addressed the problem of the high frictional forces by developing a complex die in which the floor of the exit channel moved along with the work piece. Back extrusion is considered a useful industrial method to create better surface finish, good dimensional control and lower required force comparing to the conventional extrusion.

Harnessing the outstanding capabilities of back extrusion methods, Fatemi-Varzaneh and Zarei-Hanzaki, (2009) proposed accumulative back extrusion (ABE) as a novel bulk deformation technique. A twin punch setup, designed to slide through each other, formed the heart of this novel technique. As a relatively new severe plastic deformation technique, twist extrusion requires in-depth investigation of its plastic deformation characteristics. In this study, the twist extrusion process with a square shape die cavity has been analyzed using an upper bound solution to estimate the required power, deformation pattern, and optimum process condition. The analysis has been performed based on two kinematically admissible velocity fields while the effects of friction condition, die geometry, and mean equivalent strain have been considered Seyed, et. al., 2014; Marat, et. Al., 2015; and ChengPeng, et. Al 2012. A further defining feature of SPD techniques is that the preservation of shape is achieved due to special tool geometries which prevent the free flow of material and thereby produce a significant hydrostatic pressure. The presence of a high hydrostatic pressure, in combination with large shear strains, is essential for producing high densities of crystal lattice defects, particularly dislocations, which results in a significant

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refining of the grains. As the dimensions of the work-piece practically do not change in an SPD operation, the process may be applied repeatedly to impose exceptionally high strains. The main objective of a SPD process is to produce high strength and lightweight parts with environmental harmony. In the conventional metal forming processes such as rolling, forging and extrusion, the imposed plastic strain is generally less than about 2.0.

When multi-pass rolling, drawing and extrusion are carried out up to a plastic strain of greater than 2.0, the thickness and the diameter become very thin and are not suitable to be used for structural parts. In order to impose an extremely large strain on the bulk metal without changing the shape, many SPD processes have been developed (Maki, 2001). The ultra-fine grained metals created by the SPD processes exhibit high strength, and thus they may be used as ultrahigh strength metals with environmental harmony (Azushima, et al., 2008). The yield stress of polycrystalline metals is related to the grain diameter d by the Hall-Petch equation

$$\sigma_y = \sigma_o + Ad^{-1/2} \quad (1)$$

where σ_o is the friction stress and A is a constant. Eq. (1) means that the yield stress increases with decreasing square root of the grain size. The decrease of grain size leads to a higher tensile strength without reducing the toughness, which differs from other strengthening methods such as heat treatment.

To accomplish this, a very large extrusion force is often involved resulting into adverse interface conditions which can lead to tool wear and consequent tool failure. Bay et al., (2009) stated that tribological systems depend strongly on the kind of metal forming process. Cold forging operations, especially, SPD requires a very large load which poses a high risk on tool life. This large load illustrates the need for different special lubricants, antiwear coatings and additional tribological components such as functional surfaces, to efficiently maximize tool life. Quality and type of lubrication which are required to realize tool workpiece separation and friction reduction depend strongly on the extrusion loads that appear in a specific process. By this separation, reduced tool wear is achieved because the risk of adhesion is minimized. Additionally, in most cases friction forces are reduced.

The use of conventional, petroleum-based synthetic oil as lubricants being an issue due to environmental problems, it has become imperative for researchers to be proactive in establishing safe and healthy working conditions while limiting the strain on the environment and metal forming equipment. Since about a decade ago, many countries such as Europe, Japan and the US have increasingly been restrictive to the industrial application of hazardous lubricants (Bay, et. al., 2010). Regarding cold forging, the substitution of zinc phosphate plus soap with environmentally benign lubrication systems is of concern due to sludge accumulation in the baths and its associated content of heavy metals (Bay, et. al., 2010).

The current work derived its novelty from using three punch setup designed to act sequentially. This has been applied to a commercial aluminum 6063-O (magnesium and silicon as alloying elements) received from Nigeria Aluminum Extrusion Company

(NIGALEX). This is geared towards improving structural rigidity or stability of AA6063 which is known to be a soft alloy. This becomes necessary since AA2xxx and AA7xxx series that are harder aluminum alloy series are not too common in Nigeria market. Achieving better hardness in commercial aluminum alloy 6063-O can then replace AA2000 and AA7000 series.

2. Materials and Methods

The materials used here consist of a rod of commercially available aluminum alloy (AA6063) obtained from Nigeria Aluminum Extrusion (NIGALEX) company, Oshodi, Lagos. Extrusion rig, designed and constructed, at the University of Lagos central workshop. This was assembled and using the vertical hydraulic testing machine in the stress analysis laboratory, the experiment was performed as detailed below.

2.1 Experimental Procedure

The BE die designed consists of a hollow cylindrical die with an ejector pin at the base. The die has an external diameter of 115mm, internal diameter of 35 mm and a height of 80mm. The die also has a fixed compartment on top of it which serves as centering device for the inner punch. Three separate cylindrical punches were designed to act sequentially. The inner punch has a diameter of 20mm and a height of 120mm. The second, which is a hollow punch, has a height of 90mm, internal diameter of 20mm and external diameter of 7.5mm. The third punch has a diameter of 35 mm and a height of 100mm. A commercial grade aluminum alloy (Al-6063) was employed to investigate the feasibility of the innovated back extrusion (BE) method. The aluminum was machined to a cylindrical shape of 35 mm diameter and 20mm height. The samples were initially coated with palm oil for the cup extrusion and three more lubricants namely; groundnut oil, olive oil and castor oil were introduced during the rod extrusion. The lubricated aluminum sample is placed in the entry channel of the BE die. The BE die is then placed in between the rams of the Instron servo hydraulic press with a load range of 600KN and load division of 0.5KN for each experiments. A lubricated punch is then placed on the top of the sample in the BE die, and load is applied with a constant ram displacement. During loading, extrusion pressure was recorded at each interval ram displacement.

Loading is continued till the inner punch penetrates into the aluminum billet close to its base in the cup extrusion. At this point, the load is removed and the hollow punch is introduced for the rod extrusion. During the compression, the inner punch is removed and the material flows into the gap created by the inner punch thus forming a rod-like shaped material. At the end of the deformation, the sample was taken out by the use of ejector pin. After BE, the deformed samples were prepared for hardness test using Rockwell hardness testing machine. Micro-hardness test measures the resistance to localized plastic deformation. The test consists of an indenter of known shape and size which is pressed into a material under a set load for a period of time. The indenter tip can be of any known geometry, typically a ball or pyramid shaped. The indentation

made in the material being tested is a measure of the hardness of that material. Micro-hardness testing in this research was performed using a Rockwell hardness machine with Vickers hardness tip. The tester had a pyramidal shaped tip and left a diamond shaped indentation in the sample. A load of 100g with a dwell time of 10s was used to perform the indentations. This load and dwell time setup was used because it was determined that the indentation made encompassed a large number of individual grains thus removing any anisotropy within each grain and giving the average hardness of the material. Vickers micro hardness number (Hv) was calculated from the average lengths of the diagonals along with the load used.

2.2 Stages of Accumulative Back Extrusion Processing

The 600kN vertical hydraulic press used for the accumulated back extrusion is shown in Fig. 1.

The principle of back extrusion processing is shown in fig. 2 below. In the first step the work piece is put into the die cavity (Fig. 2a). Any cycle of back extrusion consists of cup extrusion followed by a two-dimensional constrained back-pressing. These are being performed through an innovatively designed three punch setup. The punches are designed to act sequentially. In the first step the work piece is extruded into the gap between the inner punch and the die through the back extrusion process (Fig. 2b). In the second step the back extruded material is pressed back by the second punch (as a hollow ram, Fig. 2c). As the second punch is pushed down, the material flows into the gap created by the inner punch which is removed before the compression. Thus a rod with a quasi-pipe defect is formed (Fig. 2d). The latter causes the deformation to continue without any reduction in the volume of the work piece. Consequently at the end of this cycle, the initial shape of the work piece is reproduced (Fig. 2e).



Figure 1: Universal Tensile Machine

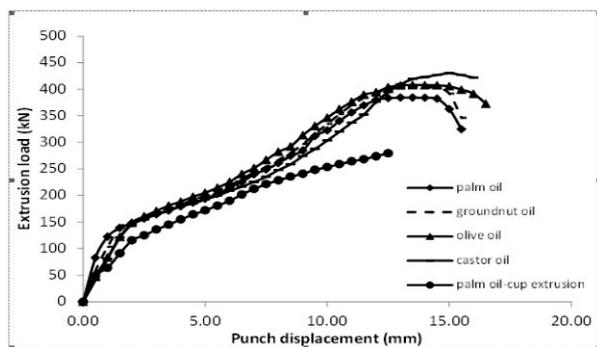


Figure 3: Load-stroke curves for accumulated back extrusion

Figure 3 shows the typical load-displacement curve obtained for the first stage of accumulated backward extrusion of aluminium 6063. Generally, it is observed that the increase in percentage height reduction leads to a proportional increase in the compression force till punch displacement of about 2mm. Beyond this point, increasing punch displacement leads to gradual, but less steep, increase in extrusion force to punch displacement of 13 mm. From here, further increase in punch displacement leads to a drop in extrusion pressure probably due to reduction of the billet length, and consequently a reduction in frictional load, in the container. It can be seen that palm oil gives the least extrusion load, followed by groundnut oil, then olive oil while castor oil gives the highest extrusion load. This shows that palm oil gives the best lubrication while castor oil is the worst lubricant during accumulated backward extrusion.

Figure 4 shows load-stroke curves during final compression back, under geometrical constraint, towards the original shape. Here, the extrusion load is lower than that of the initial stage since it is a mere collapsing of a billet of smaller diameter than the container (see Figure 2d). As deformation progresses, the metal spreads over the surfaces of compression punches to increase or decrease its diameter, frictional forces oppose the outward flow of metal depending on the performance of the lubricant applied. This frictional resistance occurs in that part of the specimen in contact with the punches, while the metal at the specimen mid-height can flow outward or inward, depending on the effectiveness or otherwise of the applied lubricant. This leads to a barreled specimen profile, and internally a region of undeformed metal is created near the punch surfaces. As these undeformed zones approach and overlap, they cause an increase in force for a given increment of deformation and the load-deformation curve bends upward.

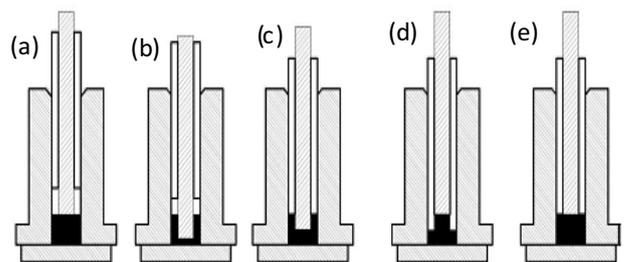


Fig. 2: Principle of accumulated back extrusion

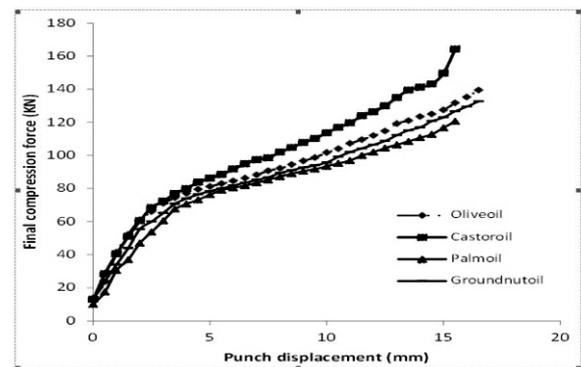


Figure 4: Load-stroke curves during final compression back, under geometrical constraint, to-towards the original shape

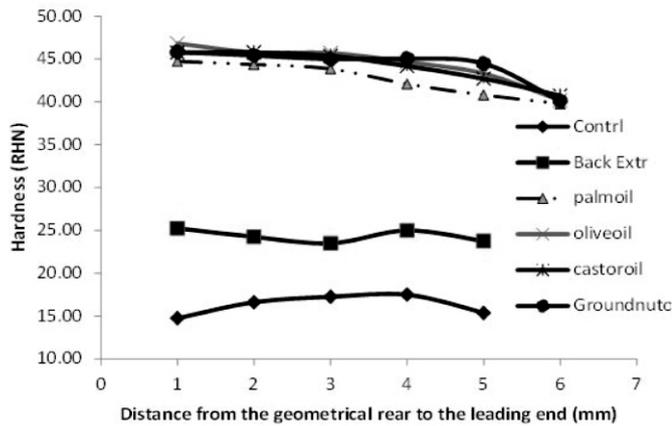


Figure 5. Brinell hardness value versus distance from geometrical rear to the leading edge

The slope of each curve is seen to be a function of performance of lubricant used. Again, palm oil gives the least extrusion load, followed by groundnut, then olive oil while castor oil gives the highest extrusion load. This shows that palm oil gives the best lubrication while castor oil shows to be the worst lubricant during accumulated backward extrusion.

Figure 5 shows the effect of lubricants on the surface hardness of aluminium 6063 processed by accumulated backward extrusion (ABE). The surface hardness values drop gradually from the geometrical rear toward the leading edge. There is significant improvement in the surface hardness of all the specimens after accumulated backward extrusion (ABE) process as compared with the control and mere backward extruded specimens. Here, specimen ABEed with palm oil as lubricant gives the least surface hardness value than specimen ABEed with olive, groundnut and castor oils. Inspection of Fig. 5 shows that there is some scatter, especially toward the leading edge, nevertheless all of the points lie within a reasonably narrow band suggesting a high degree of homogeneity which probably account for the high improvement in the hardness values. Figure 6 shows the average hardness values across the base of the deformed specimens. It is seen here that the hardness values of specimens ABEed with palm, groundnut, olive and castor oils were conspicuously lower than that at the wall or side of the specimen. The values were merely above that of backward extruded specimens. Also, the values were more scatter than that along the wall or side which shows lesser homogeneity than that at the side wall. However, all of the points still lie within a reasonably narrow band suggesting a reasonably good degree of homogeneity which probably accounts for the level of improvement in the hardness values.

4. Conclusions

This study has shown that the structural stability of Aluminium – 6063 have been improved at various degrees by applying this kind of severe plastic deformation method. The hardness of AA6063 was increased from about 15HRE to about 26HRE representing an increase of about 42% after the first stage (cup Extrusion). During the second stage (rod Extrusion), an increase of about 59% from the original hardness value was recorded taking the hardness value to about

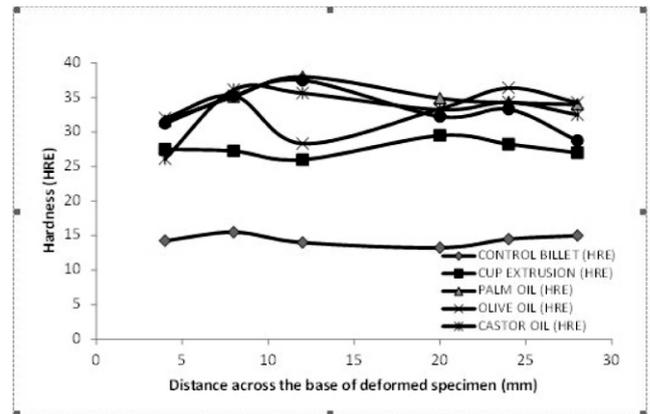


Figure 6. Brinell hardness value versus distance across the base of deformed billet after ABE

37HRE. If the first cycle gives this improvement, going through two to three cycles will almost, if not above, take the hardness value to that of 2xxx and 7xxx series. Generally, from the Rockwell hardness test carried out on the extruded billets, it can be observed that all the lubricants performed creditably well as the values were very close lying within a reasonably narrow band suggesting a high degree of homogeneity which probably account for the high improvement in the hardness values. Palm oil gave the least extrusion force.

Acknowledgement

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