Effects of lubricant on the mechanical  
properties of aluminum 6063 alloy after ECAE  
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**Abstract  
Purpose** – The purpose of this paper is to investigate the degree of improvement in mechanical properties of aluminum alloy (AA6063) after processing with equal channel angular extrusion (ECAE) using four environmentally benign lubricants.  
**Design/methodology/approach** – Aluminum (Al) 6063 bar was annealed at 350°C for 1 hour, machined and cut to billets measuring 14 14 44mm3 . These specimens for extrusions were machined to the specified dimension to a visibly good finish. The billets were extruded through ECAE die of 14 14 mm2 channel cross-section area; the channel angle was 120°; and the angle of the outer arc of the channels was 30°. The punch and container used for the experiment were made of tool steel alloy AISI D2, and were chromium-coated and polished. Four lubricants such as palm, olive, coconut and groundnut oils were used in this study.  
**Findings** – The yield, ultimate tensile strengths (UTS) and the ductility of the material ECAEed with palm oil as lubricant, which gave the least extrusion pressure, produces the maximum yield, UTS and ductility, followed by groundnut oil and coconut oil, while olive oil gave the least yield strength, (UTS) and ductility. However, palm oil and olive oil have better load reduction than other lubricants. Furthermore, from the hardness results, though scattered, all of the points at the tensile strained side of the extrudate lie within a reasonably narrow band, suggesting a high degree of homogeneity and greater hardness value within the rod than the compressive side after being ECAEed.  
**Originality/value** – It is shown in the paper that all the lubricants tested greatly enhanced mechanical properties of Al 6063 and can effectively replace the petroleum-based lubricants used in forging operations.

**Keywords:** Viscosity, Hardness, Microstructure, Aluminum, Lubricants, Forging, Yield, ECAE, Ductility, UTS  
Paper type Research paper

**1.Introduction**Processes with severe plastic deformation (SPD) may be defined as metal forming processes in which an ultra-large plastic strain is introduced into a bulk metal to create ultrafine grained metals (Valiev et al., 2000; 1993; Rosochowski and  
Olejnik, 2004; Rosochowski, 2005; Xu et al., 2006; Tsuji et al., 2003). 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 result in a significant 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 an 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 2.0, the thickness and the diameter become very thin and are not suitable to be used for structural parts. To impose an extremely large strain on the bulk metal without changing the shape, many SPD processes have been developed (Maki, 2001). The ultrafine 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 following Hall–Petch equation: y o Ad1/2 (1) where 0 is the friction stress and A is a constant. Equation (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. (2010) stated that tribological systems depend strongly on the kind of metal forming process. Cold forging operations, especially SPD, require 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 tribological loads that appear in a specific process. By this

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