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Effect of Multiaxial Forging on Properties of Aluminum Alloys – Review

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Abstract:- **The present article reviews the properties of aluminum alloys obtained through severe plastic deformation process. The multiaxial forging process one among the severe plastic deformation is considered for this review. The main objective of this paper is to learn the strengthening mechanism which is responsible for grain refinement which in turn influences the properties of aluminum alloys. The aluminum alloys are alternately forged with loading direction changed through 90° and the properties changes are reported in the technical articles. This work aims to collect some of the data and present the findings to bring the attention towards multiaxial forging process.**

Key words: Multiaxial forging, Aluminum alloys, Grain refinement

INTRODUCTION

Aluminum alloys are most versatile, economical and attractive alloy because of good combination properties. Not only the properties of these alloy but also economical leads this aluminum alloys are used in many application starting from soft application to structural applications. These are automobile industries, aerospace industries, structural applications, machines construction, pressure vessels and in numerous other areas. Almost all mechanical properties are affected formation of fine grains. The huge potential opportunity for materials grain refinement is the application of severe plastic deformation (SPD) process. In the 1990s SPD processes such as Equal Channel Angular Pressing (ECAP), Accumulative Roll Bonding (ARB) and High Pressure Torsion (HPT) processes, have attracted the attention of researchers, because grain sizes of several hundred nanometers can be obtained using these processes. Multiaxial forging is one type of SPD applied for the first time in 1990s in order to form ultra fine grain (UFG) structures in bulk material (1). The principle of multiaxial forging is illustrated in figure 1.

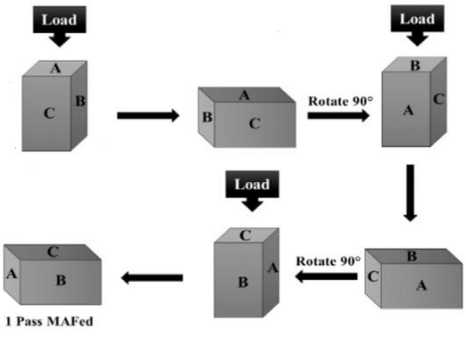

Fig.1 Multiaxial forging

The drawback of using multiaxial forging is non uniform strain distribution along the cross section of the specimen. However, this can be eliminated by using lubrication. Though the homogeneity of the strain produced by multiaxial forging is lower than in ECAP and HPT, still it is used to refine the grain size for all types of materials (2-5). This work aims to gather some of the information related to multiaxial forged aluminum alloy specimen.

MULTIAXIAL FORGED OF ALUMINUM ALLOYS

Amit joshi et al (6) investigated the mechanical properties and microstructure of Al 2014 alloy subjected to multiaxial forging to a cumulative strain of 1.2, 1.8, and 2.4. They found that cumulative strain of 2.4 shows the formation of ultrafine grain sizes in the range of 100-450 nm with high-angle grain boundaries after four passes and also improvement of tensile strength and hardness. The improvement in tensile properties of MDFed alloy is attributed to dislocation strengthening and grain boundary strengthening effect.

Cherukuri and srinivasan (7) conducted multi-axial compressions/forgings (MAC/F) at room temperature to get severe plastic deformation (SPD) of AA6061 alloy. They measured the microhardness across the cross-section of each and every pass of MAC/F process and found that the hardness distribution is not uniform during early compressions/forgings and becomes uniform with subsequent compressions/forgings.

Tomoya Aoba et al (8) investigated on the effects of natural aging and artificial aging on the mechanical properties and microstructure of multi-directionally forged 7075 aluminum alloys with cumulative strain up to 0.7. The result shows that there is an increased yield strength (+96 MPa) and ultimate tensile strength (+94 MPa) mainly due to work hardening. These samples are further aged to both natural aging at room temperature and artificial aging at 393°K and they found that the multidirectionally forged samples further increased yield strength (+190 MPa) and ultimate tensile strength (+293 MPa). They also found that the microstructure and mechanical properties resulting from multidirectionally forged samples were stably maintained for a long period of time during natural aging.

The strain rate sensitivity of multiaxial forged 6063 aluminum alloy is investigated by Lokesh vendra et al (9). They investigated strain rate sensitivity using tensile and compression test data at different strain rates, fracture toughness using three-point bend test at liquid nitrogen temperature. The hardness is increased from 60 VHN to 116 VHN, the tensile strength is increased from 220 MPa to 337 MPa and the strain rate sensitivity (SRS) is increased from 0.004 to 0.02. The improvement of these properties in multiaxially forged specimen is due to accumulation of high dislocation density at cryogenic temperature. The effective fragmentation of grains and grain refinement in the 6063 aluminum alloy is due to large plastic strain induced during cryogenic forging. They also found that the fracture toughness of the muliaxially forged alloy has been increased from 8.32 MPa $m^{0.5}$ to 13.78 MPa $m^{0.5}$ due to grain refinement and high fraction of grain boundaries.

The influences of multi-directional forging on the microstructure and property of 2099 Al-Li alloy extrusion were studied by Wu Yao et al (10). Six passes multi-directional forging was taken to 2099 Al-Li alloy extrusion samples after a pretreatment and aging treatment. The results showed that the band structure disappeared in the axial direction after multi-directional forging. In addition to this, the grain was refined and the grain size reduced from 5004.5 to 2808.6 nm and the tensile strength also improved.

The effects of solution treating and over ageing on deformation behavior of an age hardenable Al-Cu-Mg alloy (AA2024) during multi-directional forging are investigated by Saeed Khani Moghanaki et al (11). The mechanical behaviors of AA2024 alloy after multi directional forging are investigated in terms of flow stress and hardness. These results are shown in fig.2 and 3 respectively.

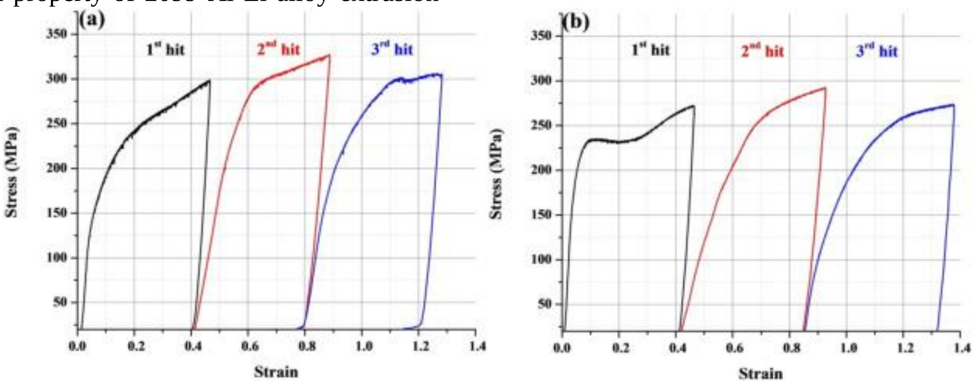

Fig.2 Flow stress (stress-strain curve) of (a) solution treated, and (b) over-aged specimens during forging. Each segment is one hit/pass of Multi Directional Forging

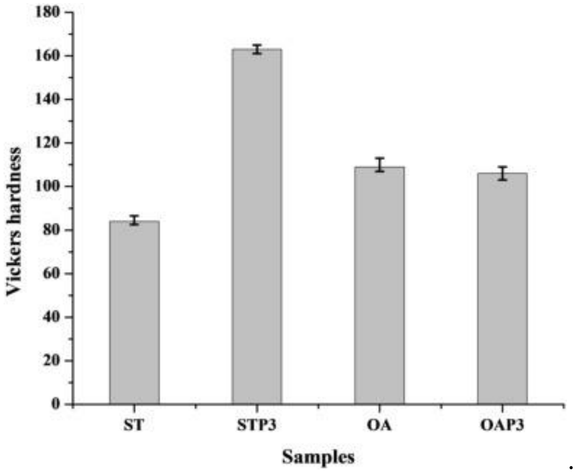

Fig.3 Hardness - solution treated (ST) and over aged (OA) specimens before MDF and STP3 - solution treated after 3 MDF passes and OAP3 - over-aged specimens after 3 MDF passes

Based on their findings, they conclude that the compressive stress during Multi Directional Forging shows an increase up to the second pass, and by further straining the flow stress is decreased in both solution treated and over-aged AA2024 alloys (Fig.2). The hardness measurements confirmed that there is no significant change in hardness before and after Multi Directional Forging in the over-aged alloy, but the hardness of solution treated samples was strongly increased from 84 HV to 163 HV (Fig.3).

Qing-feng ZHU et al (12) investigated the effect of forging passes on the refinement of high purity aluminum during multi-directional forging. They focused their studies on the structure uniformity due to deformation uniformity and the grain refinement limitation with very high strains. Based on results they conclude that fine grain zone in the center of sample expands gradually with the increase of forging passes. The grains size in the center is refined to 110 μm as forging passes reach 12, and there is no further grain refinement in the center with increasing the forging passes to 24. However, the size of the coarse grains near the surface is continuously decreased with increasing the forging passes to 24.

CONCLUSION

Based on the available literature, it is conclude that

- There are many researchers use different materials, viz, steel, stainless steel, HSLA steel, aluminum, copper, titanium, magnesium to study the effect of multiaxial forging on the properties of the materials.
- The current review covers the studies on effect of multiaxial forging on properties of aluminum alloys like pure aluminum, 2xxx series, 6xxx series and 7xxx series only.
- In all studies, researchers proved that multiaxial forging is a effective process to refine the grain size (up to nano level) of the materials thereby increasing the properties of the materials like tensile strength, flow stress, yield strength and hardness.
- Various strengthening mechanisms involved during multiaxial forging process namely dislocation strengthening and grain boundary strengthening effect, accumulation of high dislocation density.

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