Multi directional forging of commercially pure aluminum for production of ultra fine grains

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Abstract - *This paper provides an introduction in the field of severe plastic deformation (SPD). SPD methods are used to convert coarse grain metals and alloys into ultrafine grained (UFG) materials. Obtained UFG materials then possess improved mechanical and physical properties, which provide us for a wide commercial use. In this paper, to obtain ultra fine grains one of sever plastic deformation techniques called Multi directional forging was used. The effect of forging passes on the refinement of high purity aluminum during multi-forging was investigated. The attention was focused on the structure uniformity due to compressive deformation and the grain refinement. To obtain the result scanning electron microscopy and Vickers hardness test was used. The results showed that the fine grain zone gradually increased with the increase of forging passes. And with increase of passes harness value also increased.*

Key Words: *Multi-directional forging; Severe plastic deformation; Pure aluminum; Ultra fine grains.*

1. INTRODUCTION

Severe plastic deformation (SPD) is currently one of the most promising methods for processing ultrafine microstructures. Ultrafine-grained materials generally offer high strength coupled with reasonably good fracture toughness and often super-plastic properties at moderate temperatures and at high strain rates [1-6]. Especially, the low-strength commercially pure and low-alloyed metals can be dramatically enhanced by extensive grain refinement, thus offering new opportunities to exploit some attractive physical properties in metals having a reasonably high strength for structural applications. [7-10]. Severe plastic deformation (SPD) techniques, such as high-pressure torsion (HPT)[11], equal-channel angular pressing (ECAP)[11,12] and accumulative roll bonding (ARB)[13], and Multi directional forging (MDF) or multi axial forging (MAF) has been an accepted procedure for producing significant grain refinement in bulk crystalline metals [14]. MDF seems to be especially attractive in these various SPD methods, because it is the easiest method without any special device and has great potentiality for scaling up of relatively large samples that can be suitable for industrial applications [15].

The principle of MDF, i.e. multidirectional forging operation, is repeating compression process with changing the axis of the applied strain x → y →z →x → . . . at each step. Redundant plastic strains can be accumulated into the material as it is repeatedly deformed at ambient to elevated temperatures. Since a work piece changes hardly its shape under MDF conditions, many repetitive passes can be undertaken to achieve very high total strains [16].

The main aim of the present work was to study any influence on grain size as grain refinement during hot MDF. For this project two different temperatures i.e. 200˚C and 300˚C was used with three different passes i.e. 3, 5, 7. The effect of micro-structural development and the grain refining mechanisms operating during hot MDF were discussed in details.

2. EXPERIMENTAL

Some same-sized rectangular samples (20 mm×20 mm×50 mm) were cut from the as-cast commercially available aluminum (≥99.9995 %) ingot, and then forged by a 50 T hydraulic press.

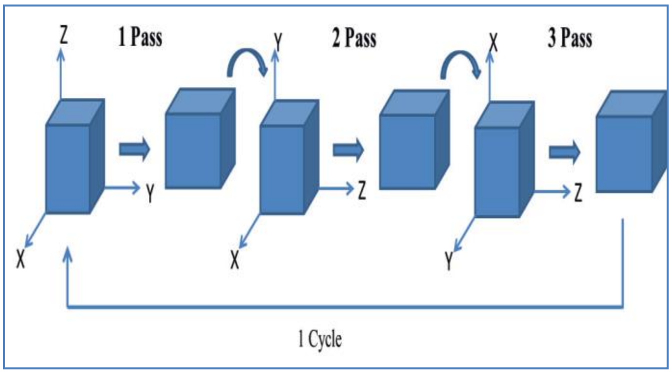


Fig. 1 Schematic diagram of multi-directional forging with different pass: (a) Pass 1; (b) Pass 2; (c) Pass 3

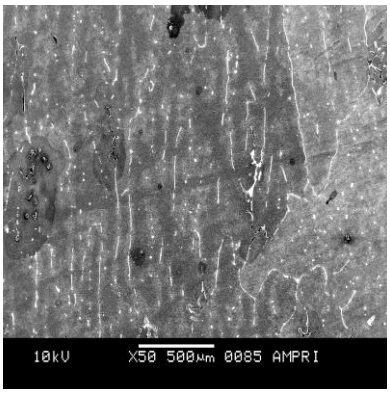
Figure 1 shows the MDF process. First, the sample was forged down along the Z direction (the long side) to 50 mm (Pass 1); then, the sample was turned 90° around the X axis and forged down along the Y direction (newly formed long side) to 50 mm (Pass 2); subsequently, the sample was turned 90° around the Z axis and forged along the X direction to 50mm (Pass 3).

Above described process was carried out for three different passes i.e. 3, 5, 7 and at two different temperature i.e.200˚C and 300˚C. Each of the forged samples was cut along the midline of the long side, then polished mechanically and etched by aqua for micro structure observation. Afterwards, some small specimens were cut from these samples. With a further grinding, polishing and oxidizing, these specimens were examined by scanning electron microscope. Vickers hardness test was also carried out to obtain the overview of enhance of mechanical properties.

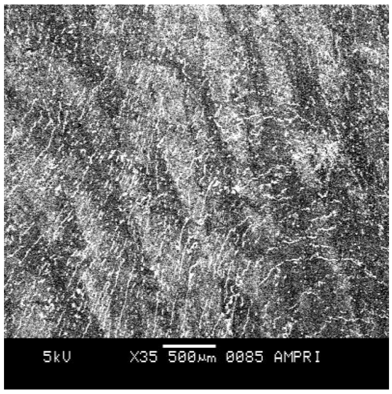
3. RESULT

3.1) Scanning Electron microscopy observation:-

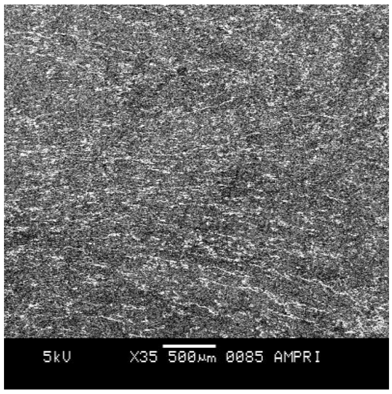
Figures 2(a) shows the microstructures of the as-cast high purity aluminum ingot forged sample. It can be seen that the initial structure of the ingot is composed of some quite large grains outlined by clear boundaries. Figures 2(b) – (d) show the microstructures of the forged samples with 3, 5, 7, passes at 200˚C respectively. It can be seen, when the forging passes increases the initial structure is completely replaced by newly formed recrystallization grains through the whole sample. However, the structure assumes severe in-homogeneity: fine grains are mainly distributed in the centers, whereas the coarse ones are located close to the peripheral regions of the samples. However, when a forging pass is applied, some deformation bands appear in the original grains and the boundaries are twisted to some extent.



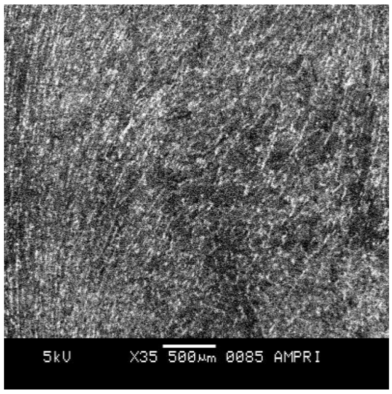
(a)



(b)



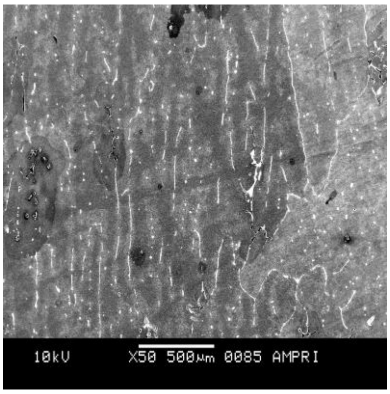
(c)



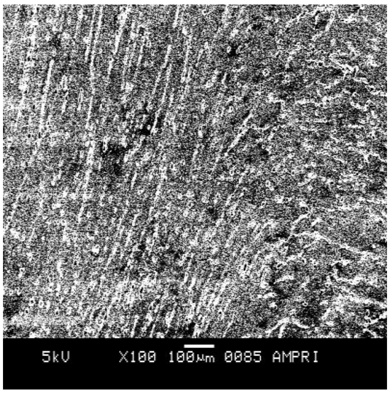
(d)

Fig. 2(a) (b) (c) (d) (a) Microstructures of work piece initial and forged with different passes: (b) 3 passes; (c) 5 passes; (d) 7 passes at 200˚C

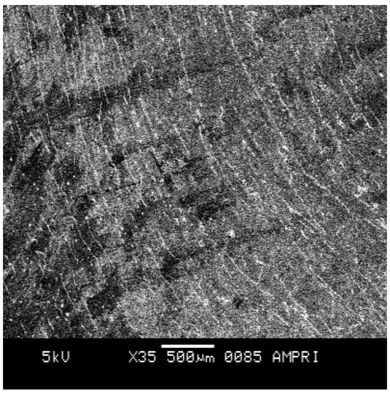
Figures 3(a) show the microstructures of the as-cast high purity aluminum ingot forged sample. It can be seen that the initial structure of the ingot is composed of some quite large grains outlined by clear boundaries. Figures 3(b) – (d) show the microstructures of the forged samples with 3, 5, 7, passes at 300˚C respectively. As can be seen, when the forging passes increases with increase in temperature i.e. 300˚C the initial structure is completely replaced by newly formed recrystallization grains through the whole sample. Due to application of higher temperature (300˚C) internal stress are relieved which leads us to have finer grains with the application of lesser load as compared to previous process.



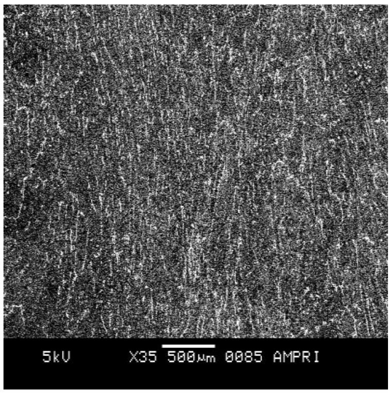
(a)



(b)



(c)



(d)

Fig. 3(a)(b)(c)(d) (a)Microstructures of work piece initial and forged with different passes: (b) 3 passes; (c) 5 passes; (d) 7 passes at 300˚C

3.2) Vickers hardness test

To test the material hardness after the multi directional forging Vickers hardness test is applied on the specimen. To obtain the better results three indentations are applied on each specimen to get the whole specimen tested.

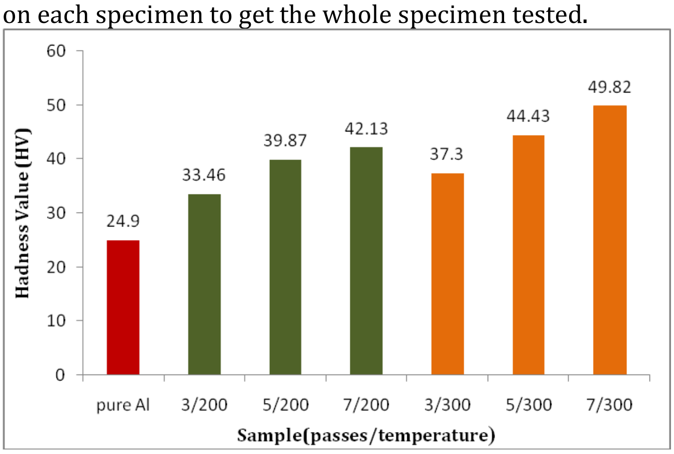


Fig 4 Hardness value (HV) of pure aluminum ingot and specimen tested at different passes and temperature.

Figure 4 shows the table of hardness obtained for different specimen at different temperature and passes.

4. DISCUSSION

As mentioned above, inhomogeneous structures are obtained when the samples are forged with different passes. This structural in-homogeneity should be determined by non-uniform MDF deformation of the samples. In the present work, each MDF pass can be simply regarded as a free forging process. Form the above SEM images it is found that initially the course grains of pure aluminum are big and grain boundaries are clearly

seen but when the passes and temperature increase the grains are converted into much finer grains and grain boundaries are very close to each other. When compared with initial structure grains are more closely packed and much fine grains are obtained.
As samples are forged at 200˚C and 300˚C and three different passes i.e. 3, 5, 7 many changes are observed such as results of samples forged at 200˚C and 300˚C and 7 passes provides better result as compared to other samples this is because due to repeated forging and heating maximum coarse grains are converted into fine grains with uniform deformation and internal stress are removed due to heating of the specimen. Grain sizes are also calculated to know the actual grain size deformation or size of formed fine grains. Figure 5 shows the grain size obtained for different temperature and passes. Form the figure it can be seen that again specimen with 7 passes shows the better result. It is found that as the passes increases formation of ultra fine grains with relatively smaller grain size are formed. Specimen with 300 ˚C shows even better result this is because due to higher temperature which leads us easy grain refinement compared to lower temperature.

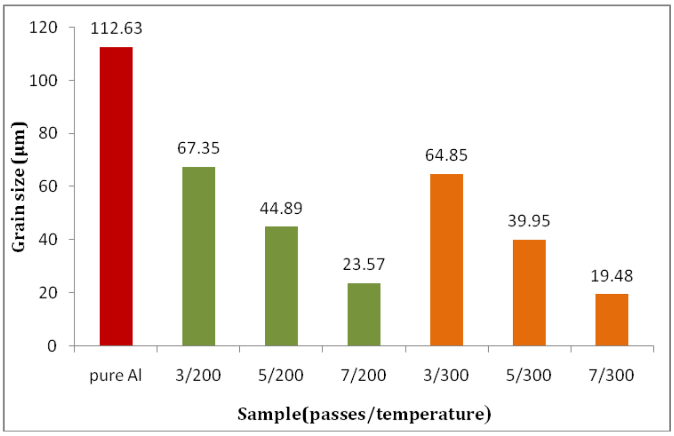


Fig 5 grain size obtained for different specimens

Hardness value obtained also shows the better result when compared with initial cast ingot. Here also specimen with 7 passes shows the better result i.e.49.82 HV as compared with initial specimen with hardness value 24.9 HV. Form this process (MDF) it is found that both grain refinement and hardness increases as the temperature and passes increases.

5. CONCLUSIONS

i. With the increase of forging passes, the fine grain zone expands gradually. As the forging passes increases coarse grains are converted into finer and finer grains. And after the 7 passes grain size is reduced from 112.63µm to 23.57µm-19.48µm.
ii. Temperature plays an important role in formation of ultra fine grains. As the temperature increases load required for the operation decreases and fine grain thus obtained are uniform. Due heating during the operation stress developed during the MDF process are also relieved and uniform grains are thus obtained.
iii. Harness of the material is also improved from 24.9 HV to 49.82 this shows that during MDF process hardness of the material is also improved.

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