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Research Article

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Comparative Study on Microstructure Evolution during Cold Forging and Warm Forging in AA6082

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Abstract

Al-Si-Mg alloys is one of the aluminum alloys in the category of light metals which are having good forging characteristics. Aluminum alloy 6082 is the heat treatable alloy having better strength among Al-Si-Mg alloys. The objective of the present work is to study the evolution of microstructure in the terms of grain sizes during cold forging and warm forging after partial solutionizing of AA6082. In addition to the microstructure evolution, the comparative study has been made between warm forging and cold forging after partial solutionizing of AA6082. Further, this study has been compared with as received AA6082. This showed that the reduction in grain sizes after partial solutionizing and cold and warm forging. Uniformity in the grain sizes was observed during warm forging. An attempt has been made in the present investigations to discuss the possible evolution of microstructures which are responsible for the mechanical properties so that relationship between microstructure evolution and mechanical properties can be developed. This further reduces the cost and time of forging process so that effective process parameters may be designed based on this for the material AA6082.

Keywords

Aluminum alloy 6082, Cold forging, Warm forging, Microstructure evolution

Introduction

Demand for light metal alloys has increased in the last few decades due to increase in the fuel prices and ease use of the components. Aluminum is one of the metals in the category of light metals. It has lower density (~2.7 gm/cc) which is next to Iron and Titanium [1]. There are varieties of aluminum alloys from 1 series to 7 series depending on the presence of major alloying elements such as copper, magnesium, silicon, zinc, etc. [1]. In this series 6 series aluminum alloys are well known for their good forging characteristics [2, 3]. In the 6 series, 6061/6063 alloys have been studied for their forging characteristics. One of the alloys 6082 in this series carries better strength due to the presence of manganese as compared to strength in 6061/6063 alloys. The advantage of Mn is not only limited to strength but also helps in grain refinement and improvement of fracture toughness [4-6]. It is a structural alloy used in aerospace and automobile industries. Design changes and using lighter materials are some strategies used by the car manufacturers. However, due to strict regulations in the aerospace and automotive industries, it is a problematic situation to determine whether a one-to-one replacement with the use of new material is possible without changing the design of the part. The AA6082 is a good candidate material for alternative to the AA6061 [7-9].

AA6082 alloy is a two-phase alloy. Previous study shows the presence of second phase Mg_2Si in this alloy. Further, this alloy is heat treatable, meaning the improvement in the mechanical properties are possible by heat treatment process i.e., solutionizing and aging. The Mg_2Si not only has better strength than that of matrix but also helps in grain refinement during solid-to-solid transformation [10]. Solutionizing causes the complete dissolution of this second phase which further reduces the strength of the material to forge this material easily. But the advantage of this phase is lost due to complete dissolution during solutionizing. Literature shows the complete dissolution of the second phase is around 500 ˚C for AA6082 [11-13]. The temperature also depends on the percentage of second phase present. Much study on forging characteristics was done with this alloy by compression test at higher temperature [14-15]. Very limited literature is available for cold forging and warm forging after partial solutionizing. The cold forging and warm forging after partial solutionizing not only reduces the cost but also reduces the time of processing. This is possible by studying the microstructural changes in this alloy. It is well known that microstructure affects mechanical properties.

So, in the present work the attempt has been made to study the microstructural evolution during cold forging and warm forging after partial solutionizing in AA6082. Further, comparison is made between different microstructures after cold and warm forging.

Materials and Methods

Material AA6082 was received in T6 heat treated condition. The weight chemical analysis was carried out to know the chemical composition of the given material. The microstructure study was carried out on the initial specimen. Further, the microstructure study was carried out on the specimens which undergone the cold forging and warm forging. The warm forging was carried out at 250 ˚C.

The as received material was cut in cylindrical shapes of size Φ13 x 37 mm^2. The first cylindrical specimen was partially solutionized at 350 ˚C for 1 hr and quenched in the water followed by cold forged under hydraulic press to a 54% deformation. The second cylindrical specimen of the same size was warm forged under the same condition of solutionizing and percentage of deformation. The percentage of deformation was kept the same to make the comparative study. The method of forging was used upsetting/open die forging. The time taken by the deformation was kept same for comparative study. The load cell is attached to the hydraulic press to read the load requirement during forging. The heating of the specimens was done in muffle furnace.

To perform the microstructure, study the standard metallography technique was used. For this, specimens were dry polished with different sizes papers ranging from 150 to 1500 Nos. Further, specimens were polished using colloidal solution of alumina powder and water on the double disc polishing machine. Specimens were etched using swab technique and with etching solution consisting of 5 ml HF, 10 ml H_2SO_4, and 85 ml water to reveal the microstructure. The microstructure analysis was carried out on the five placed of the specimens using Radical Metal 11.1 software which is attached to an inverted metallurgical optical microscope. The line intercept method and planimetric method were adopted to study the grain structure and size as per ASTM 112. The results of the quantitative metallography are reported with 95% confidence level.

Results and Discussion

The chemical composition of the alloy under study was found to be 0.97% Mg, 1.111% Si, 0.54 % Mn, and rest is Al. This confirms the AA6082 alloy as per ASTM standards. The initial microstructure of AA6082 in T6 condition is shown in figure 1. This micrograph shows a lot of variation in the grain sizes. The average grain size with the line intercept method was found to be 270 ± 16 μm. This may lead to the variation in different mechanical properties at different places which will not be suitable for any mechanical component as far as the design of component is concerned.

To study the comparative microstructure evolution of AA6082 in cold forged condition and warm forged condition, microstructure in both the conditions was taken. The grain flow after cold forging was studied macroscopically which is depicted in figure 2. This indicates the grain flow during the cold forging under hydraulic press in the form of flow lines. This also reveals that uniform deformation is happening around the center of the specimen. The un-uniformly in the deformation increases away from the center and it is more at the corner during cold deformation. A load cell attached to hydraulic press indicates lower load (2 lb/$inch^2$) at the end of warm forging as compared to cold forging (4 lb/$inch^2$).

Figure 1: Optical micrograph of AA6082 material T6 heat treated condition (As received).

Figure 3 shows the microstructure after solutionizing at 350 ˚C and 54% cold forging. The average grain size was observed to be reduced to 5.21 ± 0.23 μm in comparison to initial average grain size (270 ± 16 μm) after solutioning. The microstructure revealed the orientation of grains in one direction i.e., elongated grains in the forging direction (Figure 3). The evolution of this microstructure with this grain size could be due to cold forging and presence of second phase though the

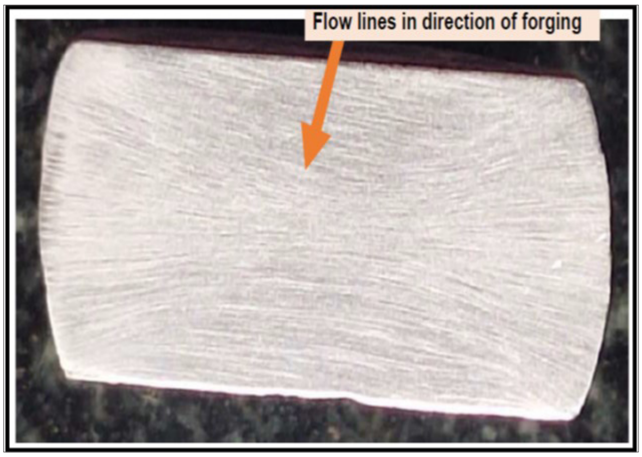

Figure 2: Specimen showing the material flow lines after cold forging.

second phase could be identified in the present microstructure. This reduction in the grain could be result of quenching during solutionizing and pinning the grain size due to the second phase due to partial solutionizing. But, to confirm this further study may be required. As per Hall-Petch equation the reduction in grain size with the presence of second phase the strength of the material increases due to this cold deformation. Further, figure 3 shows variation in the grain size, but uniformity in the grain size is achieved as compared to initial heat treatment condition. This could be attributed to partial solutionizing and distribution and size of second phase particle. This also indicates that the initial grain size before forging affects the grain size after forging.

The little increase in the grain size was observed after warm forging at 250 °C, i.e., the average grain size is increased from 5.21 ± 0.23 µm to 7.21 µm ± 0.51 µm (Figure 4). The load on the dial gauge due to load cell indicates the reduction in the load during warm forging from 4 lb/inch^2 to 2 lb/inch^2. In this case also the reduction in grain size is observed as compared to the average grain size in as received material which in T6 heat treated condition. The bar chart of number of grain sizes vs grain size number shows the more uniformity in the grain size at warm forging as compared to cold forging. In addition, the grains do not show any directional orientation in warm forging. These can be explained with the recovery and recrystallization process. The literature shows the around and above 300 °C is the recrystallization temperature for static condition [3]. The aluminum alloys are high stacking fault energy materials So, the dynamic recovery dominates before the dynamic recrystallization. High stacking fault energy materials consist of lower distance between the partial dislocations which can easily be slipped/annihilated during the deformation, or they can reorient themselves to a minimum energy condition. In that process the grains having high angle grain boundaries also orient to give more uniformity in the grain structure [16-18]. This not only improves the mechanical properties but also improves the uniformity in the mechanical properties throughout the materials in the component. Also, due to reduction in the grain sizes the strength of the materials improves at room temperature as per the Hall-Petch equation [19-20]. The second phase and reduction in grin size both possibly making the contributing towards in the improvement in the strength.

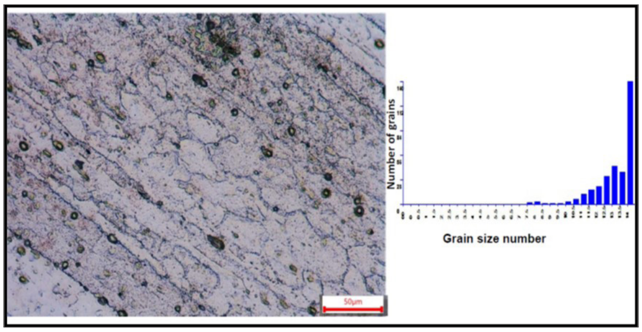

Figure 3: Optical micrograph showing directional grains with distribution for the specimen undergone partial solutionizing and cold forged to 54%.

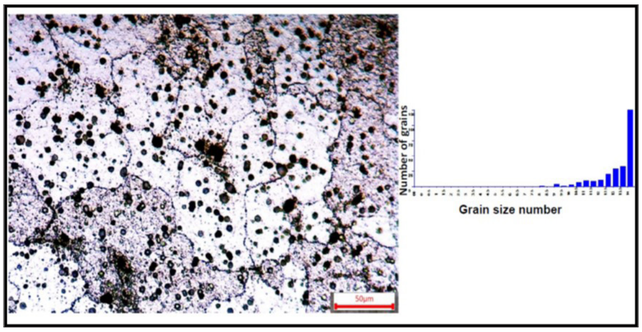

Figure 4: Optical micrograph showing grains for the specimen undergone partial solutionizing and warm forged to 54% at 250 °C.

The above conditions serve the purpose of using aluminum alloy for the lightweight application where the warm forging gives rise to improvement in the strength to weight ratio (specific strength) with uniform mechanical properties. This further reduces the chances of failure of the component due to less stress concentration facture which usually arises due to non-uniform mechanical properties throughout the cross section of the mechanical component. This carries the additional advantage in terms of processing during forging since less load requirement during forging due to prior partial solutionizing. That also improves the forgeability of the materials under study i.e., improvement in the ratio deformation per unit energy requirement. In the optimum way, the component can be by forging process with less cost and less time.

Conclusion

Cold forging and warm forging after partial solutionizing show the decrease in the grain sizes as compared to as received material AA6082 which is in T6 heat treated condition. The microstructure evolved indicates the uniformity in grain structure has been improved after warm forging with small increase in grain size as compared to that of cold forged material. The evolution of microstructure is predicted to be due to the presence of second phase as reported in literature though the second phase is not identified with this study. The uniform mechanical properties predicted to be improved in warm forging after partial solutionized AA6082 alloy with the help of microstructure evolution and presence of second phase with equal distribution. The extended study is required to understand the effect of second phase and mechanical properties of the alloy under study for these different conditions.

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Conflict of Interest

The authors declare no conflict of interest that are relevant to the content of this article.

Credit Author Statement

Rahul R. Kulkarni: Conceptualization, Methodology, Investigation, Analysis, Writing - original draft manuscript, Writing - review and editing, Supervision; Vishal L. Chakote: Experimentation, Writing - original draft manuscript; Vaibhav V. Shevale: Experimentation, Writing - original draft manuscript. All the authors read and approved the manuscript.

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