Microstructure and Induced Defects of 6061 Al Alloy after Short Times Cyclic Semi-Solid Heat Treatment

N.Fathy[1a*], M. Ramadan[2,3b], K. M. Hafez [2,3c], A.S. Alghamdi[2d]and K. S. Abdel Halim[2,3e]

[1]Physics Department, College of Science, University of Hail, P.O. Box 2440, Hail, Saudi Arabia

[2]College of Engineering, University of Hail, P.O. Box 2440 Hail, Saudi Arabia

[3]Central Metallurgical Research and Development Institute (CMRDI), 87 Helwan, Cairo, Egypt

[a*]naglaaf2002@yahoo.com, [b] mrnais3@yahoo.com, [c]k.hafez@uoh.edu.sa,

[d]a.alghamdi@uoh.edu.sa,[e]k.abdulhalem@uoh.edu.sa

Abstract. Short times (5 min. /cycle) cyclic semi-solid heat treating process up to four cycles for 6061 aluminum alloy was studied. The microstructures of as-received and cyclic semi-solid heat treatment at the edge of samples at 630◦C for one to four cycles were investigated.Short time cyclic heat treatment up to two cycles improves the microstructure to be finer and more globular compared with as-received one. Short time cyclic heat treatment significantly affects the microstructure at the edge of samples only due to short time heating.Optimum values of grain size and grain sphericity at the edge of samples for short cyclic heating time (5 min./cycle) of about 160 μm and 0.57 respectively. Increasing the number of heat treatment cycles above three increases both shrinkage porosity and micro-cracks formation.

1 Introduction

The required strength of an alloy is concerned by the design that often taken to develop it. The structure consists of particles which impede dislocation motion dispersed in a ductile matrix. It is well known that for the same amount of particles, the finer the dispersion, the stronger the material. Such dispersion can be obtained by choosing an alloy which, at elevated temperature, is single phase, but which on cooling will precipitate another phase in the matrix [1]. A heat treatment should be developed to give the desired distribution of the precipitate in the matrix. 6061 Al alloy considered in this paper is one of the widely used Al alloys. The mechanical properties of 6061 Al alloy being mainly controlled by the hardening precipitates contained in the material. When the material is subjected to a solution heat treatment followed by a quenching and a tempering treatment, its mechanical properties reach their highest level and become very good compared to other Al alloys. The as-obtained microstructure of the material is called T6 temper (tempering around 175 ◦C).

* Corresponding author:naglaaf2002@yahoo.com

Another interesting characteristic of the 6061 Al alloy is its good weldability. Because of these favorable properties, the 6061 Al alloy is used in the transport and the public works domains and also for complex structures assembled by welding [2–3].

Intensive work of semi-solid heat treatments [4-5] is aimed to develop and improve structure and properties of 6061 Al alloy. Microstructure of semi-solid isothermal heat treated 6061 Alloy has been studied**.** It was found that the optimal partial remelting parameters should be 630°C and 10–15 min for 6061 alloy cold rolled with 60% reduction in height of pre-deformation, otherwise, increasing the heating time above 15 min increase the chance for grain coarsening [4].

Previous work [6] on cyclic Semi-Solid Heat Treatment of 6061 Al alloy for long times (10 to 50 min.) have been studied. Cyclic semi-solid heat treatment results in a relatively finer and more globular non-dendrites microstructure compared with isothermal heating one for all heating time conditions (10 to 50 min.). Coarsening and cracks defects were appeared for long heating time of 40 and 50 min. Regarding those mentioned above and depending on the previous work [6] recommendations, this work is carried out to study microstructural (grain size and gain grain sphericity) evolution of 6061 Al Alloy during short heating times (5 min for one to 20 min. for four cycles) cyclic Semi-solid heat treatment to obtain the optimum of grain size and grain sphericity microstructure.

2 Experimental

Aluminum alloy in the present study was the commercial rod 6061-T6 (Cu 0.15-0.4%, Mg 0.8-1.15%, Mn 0.12%, Zn 0.25%, Cr 0.04-0.35%, Ti 0.15%, Si 0.4-0.8%, Fe 0.7%) of 20 mm diameter. The measured solidus and liquidus temperatures are 582.8°C and 652°C, respectively as indicated by pervious study using differential scanning calorimetric analysis (DSC) for the semi-solid 6061 alloy [3]. Specimens of approximate dimensions φ20x20 mm rod were cut for short time (ranged 5 to 20 min.) cyclic heat treatment as well as microstructure examination and hardness measurements. For cyclic heat treatment, the samples treated for one cycle after 5 min holding at 630 ^{0}C were cooled to a temperature of 536 ^{0}C in still air cooling and then quenched in water. the samples treated for two cycles after 5 min holding at 630 ^{0}C was cooled to a temperature of 536 ^{0}C in still air cooling and then was heated again to 630 ^{0} C for next 5 min heating time followed by cooling to a temperature of 536 ^{0}C in still air cooling and then quenched in water. the samples treated for three and four cycles after 5 min holding at 630 ^{0}C were cooled to a temperature of 536 ^{0}C in still air cooling for three and four times respectively, and then quenched in water (see Fig. 1).

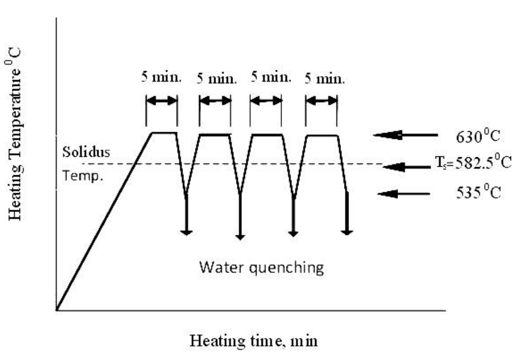

Fig.1. Schematic illustration of the applied short time cyclic semi-solid heat treatment process.

Specimens in either as received or cyclic heat treated condition were grinded, polished, etched with a solution consist of 2% HF, 25% HNO_3 and 73% H_2O and examined metallographically using an optical microscope and photomicrographs were taken. Grain size and grain sphericity were measured and analyzed with Scentis image analyzer software (with errors 5%).

3 Results and Discussion

Fig. 2 shows the macrostructure of as- recived and cyclic semi-solid heat treated 6061Al alloy. It is clear that cyclic semi-solid heat treatment has improved the macrostructure homogeneity of 6061 Al alloy.Microstructure of as- recived 6061alloy at the center, interface and edge of samples respectively is shown in Fig.3.It can be seen that the grains of the as-received 6061 Al alloy clearly exhibits the rosette character for micrograph took for area at the edge and near the edge of specimen but exhibits near spheroid for area at center of specimen. The difference between edge and center macrostructure pattern which revealed a well bounded central region are resluted oftenly from the production process of as- recived samples.

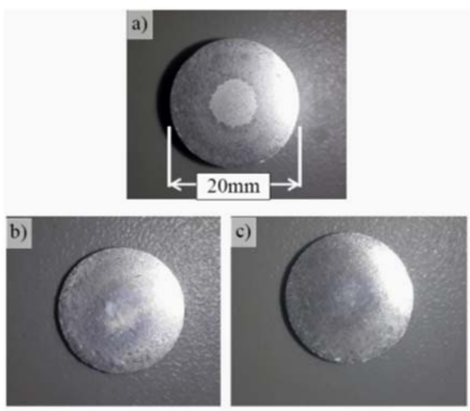

Fig. 2 .Macrostructure of a) as- recived 6061alloy and semi-solid cyclic heat treatment for heating time of 5 min. b) two cycles and c) four cycles respectively.

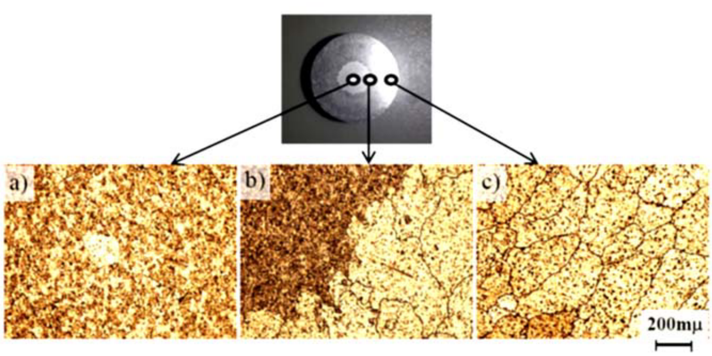

Fig.3. Microstructure of as- recived 6061alloy at the a) center, b) interface between center and edge c) edge of samples respectively.

The microstructures of as-received and cyclic semi-solid heat treatment of 6061Al alloy at the edge of samples at 630◦C for one to four cycles are shown in Fig. 4. In this study, microstructures of both as-received and cyclic semi-solid heat treated ones in the center of sample showing nearly no significant differences. Short time heat treatment could be the reason of this accordingly such treatment affects significantly on the edge of the heat treated samples. In generall, it can be observed that the short time cyclic heat treatment improved both the grain size and grain sphericity compared with the as -recived samples. Fig.5 shows the average grain size and grain sphericity as a function of number of heat treated cycles. Up to two cycles, the gain size decreases and gain sphericity increases with increasing the number of cycles. For applying three and four cyclic semi-solid heat treatment, slight effect on gain size and gain sphericity are observed.

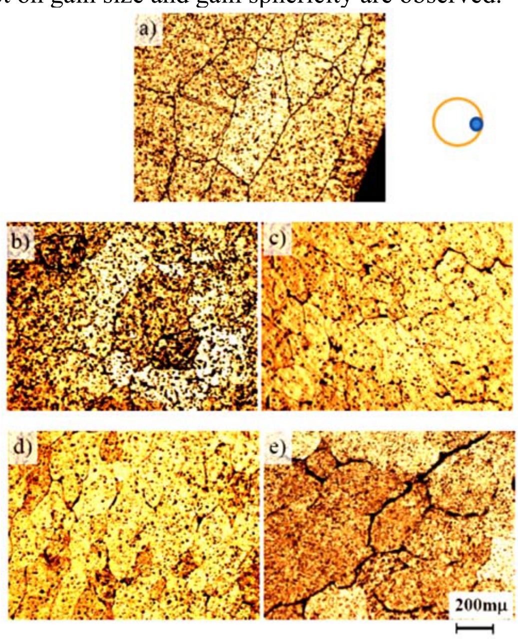

Fig.4 Microstructure of a) as- recived 6061alloy and semi-solid cyclic heat treatment at the edge of samples for heating time of 5 min. b) one cycle, c) two cycles d) three cycles and e) four cycles respectively.

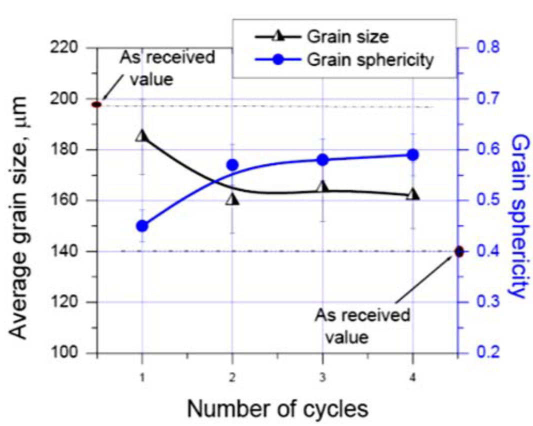

Fig.5. Average grain size and grain sphericity as a function of number of heat treated cycles.

It was indicated [5] that coarsening first proceeds through the coalescence of dendrite arms during partial melting and then holding. After coalescence, phase coarsening will take place through the dissolution of the small globules and the grain numbers will then decrease.

During partial re-melting [4], the heating of the alloy up to the semisolid temperature at which the solid and liquid phases coexist in equilibrium results in the desirable liquid fraction through the control of temperature. However, a long-time holding often results in the coarsening of grains, which is detrimental to the mechanical properties of produced parts. Previous study [6] on cyclic semi-solid heat treatment of 6061 Al alloy for long times range (10 to 50 min.) stated that during the cyclic heat treatment, the heating time (10 min./cycle) followed by cooling will relatively decrease the rate of precipitates migration to liquid compared with the isothermal semi-solid one. The relatively high precipitates remain in solid phase could be the reason of relatively decrease in the coarsening rate in cyclic heat treatment. In the present work, optimum values of grain size and grain sphericity for short cyclic heating time (5 min./cycle) of about 160 μm and 0.57 respectively could be reached after two cycles of heat treatment. On the other hand, in long time heat treatment [6], optimum values of grain size and grain sphericity without cracks and coarsening for cyclic heating time (10 min./cycle) of about 125μm and 0.6 respectively could be reached after two cycles of heat treatment. According to the above investigated data the semi-solid cyclic heat treatment of heating time (10 min. /cycle), a relatively finer and globular gain structure of 6061 Al alloy could be achieved compared with the current short time cyclic semi-solid heat treatment one.

In short cyclic heating time (5 min./cycle), it can be deduced that 5 min. heating time is not enough time for optimum improvement of both grain size and grain sphericity of 6061 Al alloy microstructure. Also, the repetition of this short cyclic heating time (5 min./cycle) cannot significantly improve the microstructures because the fraction of liquid that could be formed during heating in semi-solid state will be transformed again to solid upon cooling and upon heating again for second cycle nearly the same fraction of liquid will be existed.

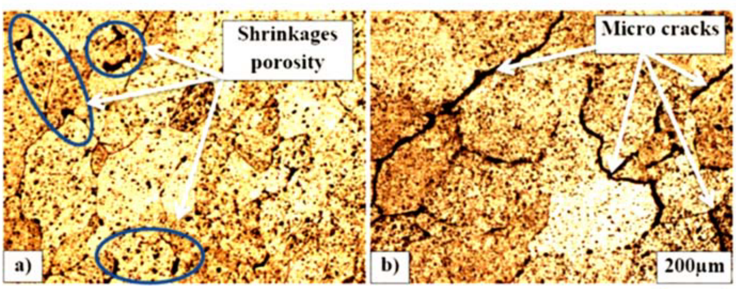

Fig.6 Shrinkages porosity and microcracks induced after semi-solid cyclic heat treatment for 6061Al alloy, a) three cycle and b) four cycles.

After three and four cycles of semi-solid heat treatements, Shrinkages porosity and microcracks clearly observed in all 6061Al alloy samples (see Fig.6). Privous work [7-9] on porosity defect induced by semi-solid isothermal heat treatment and casting processes of hypereutectic Al- Si Alloys were investigated. Much attention was paid to the relation between holding time in semi-solid state and bulk density, total porosity and pore sizes of each treated sample.In the heat-treatment of aluminum alloys, dimensional changes are one of its metallurgical natures, which arise from the introduction and relaxation of stresses, recrystallization, and solution or precipitation of alloying elements. Apart from the reversible, simple temperature and thermal expansion coefficient-related dimensional changes that take place, expansions and contractions of a more permanent type can occur during heat treatment [10].

In the present study, the heat treatment of 6061 Al alloy in semi-solid state result in the presence of liquid in the mixture of liquid- solid will give the chance to both shrinkage and cracks formation during the relatively fast cooling from semi-solid to solid state transformation. Hence, any changes in the shrinkages porosity and cracks formation reasonably could be assumed to be mainly due to the increasing of the number of semi-solid heat treatment cycles. Also the cracks formation could be explained by the thermal fatigue action during short time semi-solid heating followed by cooling to solid state.

4 Summary

Microstructure and induced defects of 6061 Al alloy after short times cyclic semi-solid heat treatment were investigated, which led to the following conclusions:

1. Short time cyclic heat treatment up to two cycles improves the microstructure samples to be finer and more globular compared with as-received one.
2. Short time cyclic heat treatment significantly affects on microstructure at the edge of the samples only due to short time heating.
3. Optimum values of grain size and grain sphericity at the edge of samples for short cyclic heating time (5 min./cycle) of about 160 m and 0.57 respectively
4. Increasing the number of heat treatment cycles above three increases both shrinkage porosity and micro-cracks formation.

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