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Control of Grain Size and Age Hardening in AA2618 Forgings Processed by Rapid Infrared Radiant Heating

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Abstract

The effects of rapid infrared (RI) radiant processing on the microstructure and mechanical properties of AA2618 aluminum forgings were investigated. Extruded bars were forged after RI-preheating to 425 °C and solutionized at 530 °C also in a RI furnace for different soaking times. Rapid preheating prior to forging produced grain sizes about 27-32μm in solutionized specimens while conventional furnace preheating produced coarser grain sizes (~40μm) in the same 2618 alloy. Use of RI preheating for forging and subsequent solution heat treatment produced sufficient age hardening in 2618 forgings. RI processing potentially leads to energy-efficient, low cost commercial production.

Introduction

Forging is a low cost near-net shape manufacturing process for high-performance parts, but the current practice suffers from inefficient energy utilization caused primarily by the use of energy-inefficient furnace preheating of forging stock. Thus, a more efficient, non-conventional heating means is highly desired to make forging a more competitive manufacturing process. This may be achieved by adopting infrared radiant heating. Rapid Infrared (RI) radiant heating is an energy efficient and environmentally friendly method for heating materials, which potentially leads to significant cost and energy savings in materials production and manufacturing [1, 2]. The RI system being developed at Oak Ridge National Laboratory [2], powered by an array of tungsten-halogen filament high-density infrared (HDI) lamps, ideally suits rapid preheating of aluminum forgings. Successful application of RI processing to aluminum forgings production, however, requires optimization for energy conservation, productivity and product quality at once. Preliminary results of RI processing tests with AA2618 forgings are reported in the present paper.

Experimental

Extruded aluminum 2618 alloy billets 2.25” in diameter, 6” in length preheated with a hybrid RI furnace and additional billets preheated in a conventional convection furnace were upset forged with a reduction ratio of 2 to 1. The hybrid RI furnace combines infrared radiant heating with forced convection to assure rapid, uniform heating. RI preheating was done with a ramp-up time to the forging temperature (425° C) of 16 minutes followed by immediate forging. Preheating with a convective furnace was done at 425° C for 2.5 hours. In commercial practice, preheating time often exceeds 8 hours depending on the lot size. The forgings were then solution-heat treated at 530 °C in a RI furnace for 1 to 40 minutes or in a conventional furnace for 2.5 hours, and aged for 20 hours at 200 °C (which produced a T61 temper,) except for one that was naturally aged at room temperature. Table I summarizes the processing conditions. Metallographic characterization and hardness testing were performed at the center of transverse cross-sections of the forgings. Tensile tests were performed at room temperature using 2.5 mm thick flat specimens 6.0 mm in width and 15 mm in gage length, cut longitudinally from the center of the forgings.

Results and Discussion

Grain refinement by RI heating

Table I lists the average grain size and hardness values of the heat treated specimens. Fig. 1 shows micrographs of RI-processed (RI-40) and conventionally processed (C-C) specimens. Specimen RI-40 shows a significantly smaller grain size (~27μm) than Specimen C-C (40μm). The smaller grain size in the RI-processed specimen resulted from grain boundary pinning during the solution treatment by intermetallic particles as seen in Fig. 1(a). Grain boundary pinning was not as effective in Specimen C-C, Fig. 1(b). These particles were determined by energy-dispersive X-ray spectroscopy (EDS) and X-ray diffraction

Table I: Processing conditions, grain size and hardness values of AA2618 forgings

Specimen	Preheating	Strain Rate Sec^{-1}	Solution Heat Treatment	Aging	Grain Size[1] (μm)	Hardness[2] (HRB)
RI-1	RI, 16mins, 425 °C	0.5	RI, 1 min.	Conventional	28	60.0
RI-40	RI, 16mins, 425 °C	0.5	RI, 40 mins.	Conventional	27	67.7
RI-40NA	RI, 16mins, 425 °C	0.5	RI, 40 mins.	Natural	32	62.1
RI-C	RI, 16mins, 425 °C	0.5	Conventional	Conventional	27	58.9
C-C	Conventional, 425 °C	0.5	Conventional	Conventional	40	59.5

1. Grain size measured by linear interception. Listed are transverse cross-section grain sizes.
2. Listed are hardness test results on transverse cross-section.

to be Al_9NiFe. RI preheating leaves more grain boundary pinning particles undissolved in the matrix, which then produces stronger pinning effects during solutionizing.

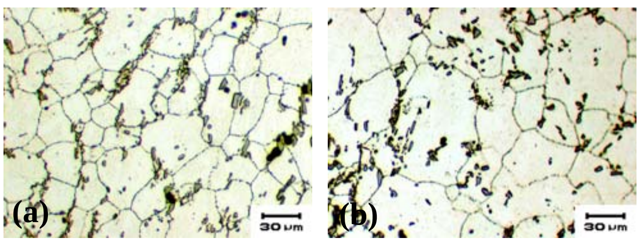

Figure 1 Micrographs of T61 forgings: (a) RI-processed specimen RI-40 and (b) conventionally processed specimen C-C.

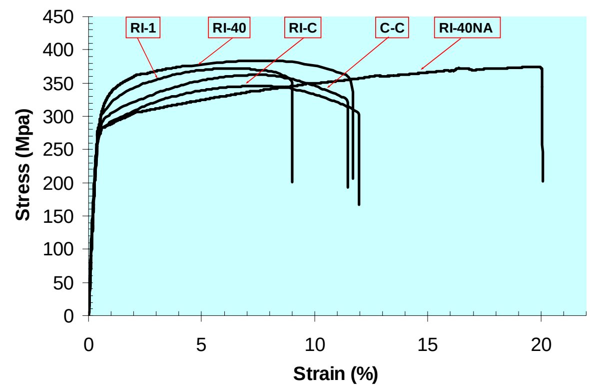

Figure 2 Stress-strain curves of heat-treated specimens.

Mechanical properties

Higher yield strength, UTS and hardness values were obtained with RI-forged and T61 treated specimens than with those processed conventionally as shown in Table I and Fig. 2. The RI-processed and naturally aged specimen (RI-40NA) showed a somewhat lower yield strength and a much larger elongation. The improved strengthening in the RI-processed specimens is primarily caused by stronger age hardening, and not by the grain refinement. Al_9FeNi, during prolonged heating, might pick up some copper [3] from the matrix, possibly releasing some nickel or iron into the matrix. This could decrease the potential for age hardening that occurs by the precipitation of the (Cu, Mg) rich GPB zones and S' (Al_2CuMg) [4] in two ways. The incorporation of copper in Al_9FeNi directly depletes copper from the matrix, while possibly releasing some of the iron and/or nickel into matrix. The released nickel and iron may form stable compounds containing copper, such as $(CuFe)Al_3$ and AlCuNi in Al-Cu-Mg alloys [3], which further depletes copper from the matrix. Further work is underway to determine the cause of enhanced age hardening in RI-processed 2618 forgings.

Conclusion

RI heating for forging and solution treatment produced finer grain sizes in 2618 forgings than in conventional processing due to increased grain boundary pinning effects of undissolved Al_9FeNi particles. Stronger age hardening occurred in RI-processed T61 forgings than those processed in a conventional convective furnace. A hypothetical mechanism for the increased age hardening in RI-processed 2618 forging was presented based on partitioning of Fe, Ni and Cu among the intermetallic phases and the matrix. The results of this investigation suggest that RI-processing may lead to low-cost, energy-efficient manufacturing of high-performance 2618 forgings.

Acknowledgment

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