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Effect of Forced-air Cooling on Semi-solid Extrusion of Mechanically Stirred Al-10%Mg Alloy Billet

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Abstract

In order to improve the poor tensile properties of Al-10wt%Mg alloy bars semi-solid extruded at higher speeds, forced-air cooling treatments were made at the constant extrusion ratio (R_e) of 36. When the constant quantity of forced-air (V_{ac}) blew the extruded bars at various positions (L_{ac}), the most improved tensile properties could be obtained at L_{ac} =70mm under the condition of extrusion temperature (T_e) of 803K and press ram speed (V_R) of 10mm/s. The optimum L_{ac} to get the improved results for each different extrusion condition existed; the higher the T_e or V_R , shorter the L_{ac} or larger V_{ac}.

1. Introduction

Semi-solid extrusion process of aluminum alloys has generally been believed to possess a several important advantages in comparison with the conventional hot-extrusion process, i.e., low extrusion force, high fluidity of material, low friction force between material and tool, etc. According to these benefits, its applications to the extrusion products with various complex sections, the high efficiency extrusions of high strength alloys, the prolongation of tool life, the miniaturizations of working plants and so on have been expected to become possible. Nevertheless, little efforts on semi-solid extrusion process have actively been carried out, except for some works including the author’s trials [1-8].

The authors have demonstrated previously [6] that the extrudability in semi-solid extrusion (thixo-extrusion) of A7075 ingots with a non-dendritic globular structure is much better than that with a dendritic structure, and that age-hardenability of bars extruded at higher speeds is compatible to that of hot-extruded ones. Superior extrudability has been obtained for semi-solid extrusion of A2014 and Al-10wt%Mg alloy billet with a globular structure [7, 8]. These suggest that the use of alloy material with a non-dendritic structure is greatly favorable in the semi-solid extrusion process as well as in the thixo-casting process. In all kinds of alloy bars extruded at higher press ram speeds, however, the tensile elongations were very small and tensile strengths were much lower than that of the conventional hot-extruded ones in the as-extruded condition [6-8].

This results in an extremely poor ductility in the T6 condition in spite of a satisfactory age-hardenability [6]. Therefore, it is important to improve the ductility in the as-extruded condition in order to find practical applications for these semi-solid extruded bars.

In this investigation, a simple forced-air cooling treatment in the die-outlet zone was adopted to the semi-solid extrusion of a Al-10wt%Mg alloy billet with a globular (non-dendritic) structure, and an improvement of poor tensile properties of the extruded bars has been attempted by changing air blowing positions at a constant quantity of blowing air.

2. Experimental Procedure

Semi-continuously cast Al-10wt%Mg alloy billets of 51mm diameter with a globular structure as shown in Figure 1(a) were manufactured by the mechanical stirring treatments in zones containing relatively high fractions of solid fractions [6-8]. The chemical composition of magnesium in the cast billets was in the range 9.5 to 10.5wt%. Cylindrical specimens with a diameter of 30mm and a length of 40mm, machined from the billet, were semi-solid extruded into round bars with a diameter of 5mm (extrusion ratio (R_e) of 36) using a speed-controlled hydraulic press (max. force: 200kN) equipped with an induction heating unit. After each specimen had been reheated to the given temperatures for about 600s and then held for 300s, extrusions were carried out at extrusion temperatures (T_e) of 803 and 823K. Ram speeds (V_R) of 10 and 20mm/s were used.

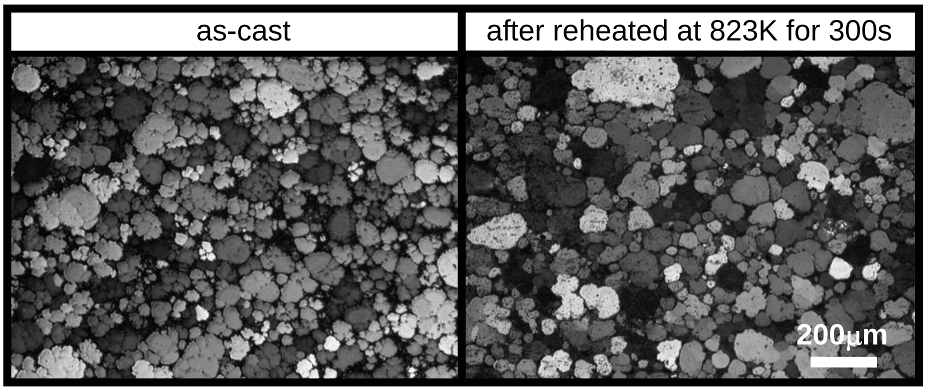

Figure 1: Optical microstructures of the Al-10%Mg billet.

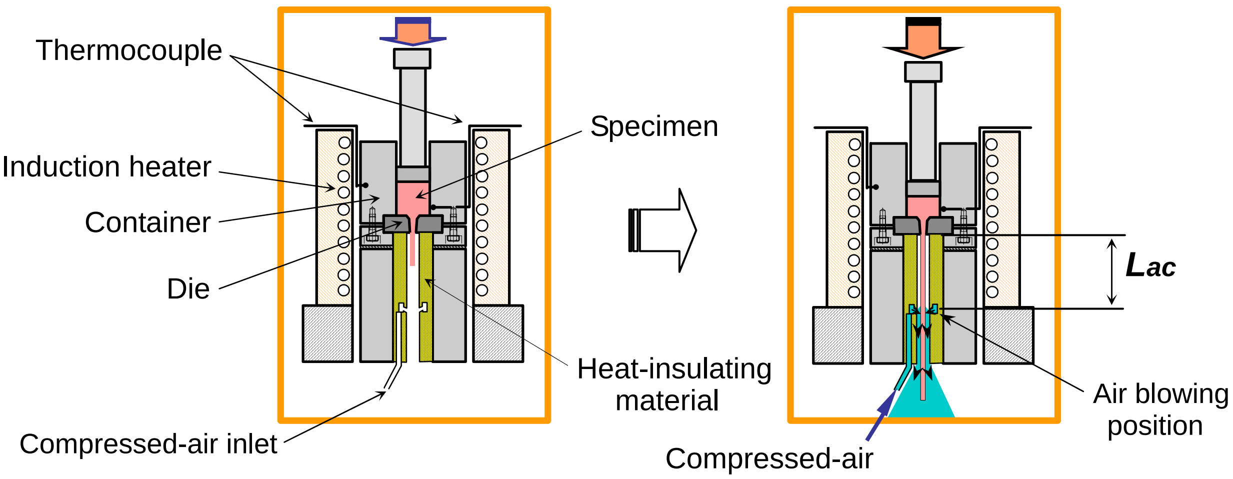

Figure 2: Schematic illustration of a force-air cooling method used.

It was estimated that the solid particles in the reheated semi-solid conditions were typically of fine globular, as shown in Figure 1(b). The solid fractions at these two T_es were estimated roughly 95% and 85%, respectively. Forced air-cooling treatments during extrusions were made using the constant air quantity of 80*l*/min (V_{ac}) at the different positions from the die-outlet, as schematically shown in Figure 2. The air blowing positions (L_{ac}) were changed in the range 30 to 140mm from the die-outlet. The round bar specimens with a diameter of 3mm and a gage length of 18mm machined from the extruded bars were tensile-tested at crosshead speed of 1mm/s within 12 hours after extrusion.

3. Results and Discussion

Under the condition of constant blowing-air V_{ac} = 80*l*/min, every bars extruded at the different T_e and V_R had the sound surface without any cracks, despite the difference in blowing position L_{ac}. Figure 3 shows examples of surface conditions of the bars extruded at lower T_e and V_R . Although each surface is similar to that for the hot-extruded one at low magnification, it commonly has the fine granulated patterns that seem to be intrinsic to the semi-solid extrusion, as can be seen from the higher magnified images. There scarcely exists a remarkable distinction of the surface condition between the bars extruded with and without forced-air cooling. Similar results were obtained at the higher V_R (=20mm/s) or at both higher V_R and T_e (=823K).

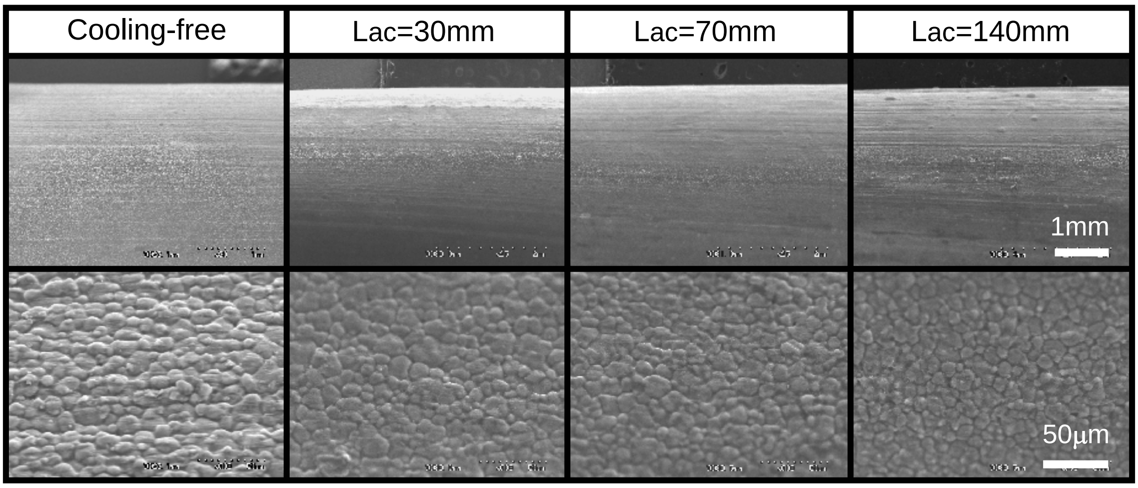

Figure 3: SEM images of the bars extruded at T_e =803K and V_R =10mm/s without and with forced-air cooling at various positions.

Figure 4 shows the effects of L_{ac} on the press force during extrusion which produced sound surfaces shown in Figure 3. Between these curves, there also seems to be no marked difference. This tendency was the same as that for another V_R and T_e. Therefore, it could be seen that, for any at constant V_{ac} = 80*l*/min, even when L_{ac} was the shortest (30mm), forced-air cooling didn't cause a reduction in material temperature which might result in a considerable increase in extrusion force. In addition, no large difference in the optical microstructures was observed, as shown in Figure 5. This means that all material flows or deformation behaviors are almost same during extrusions with and without forced-air cooling at the constant T_e and V_R. This is also derived from the fact that the material temperatures didn't fall off until the material had passed through the die.

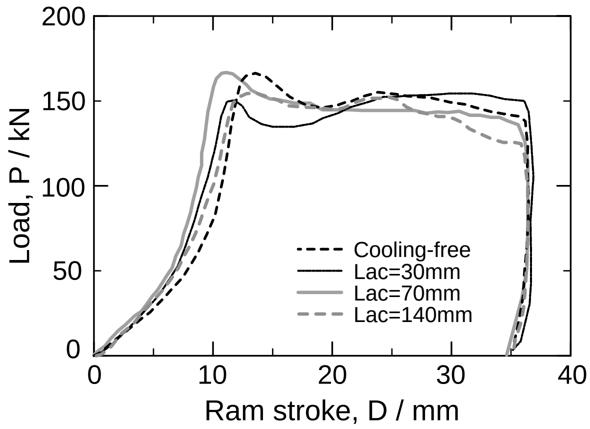

Figure 4: Load-ram stroke curves during extrusion corresponding to Figure 3.

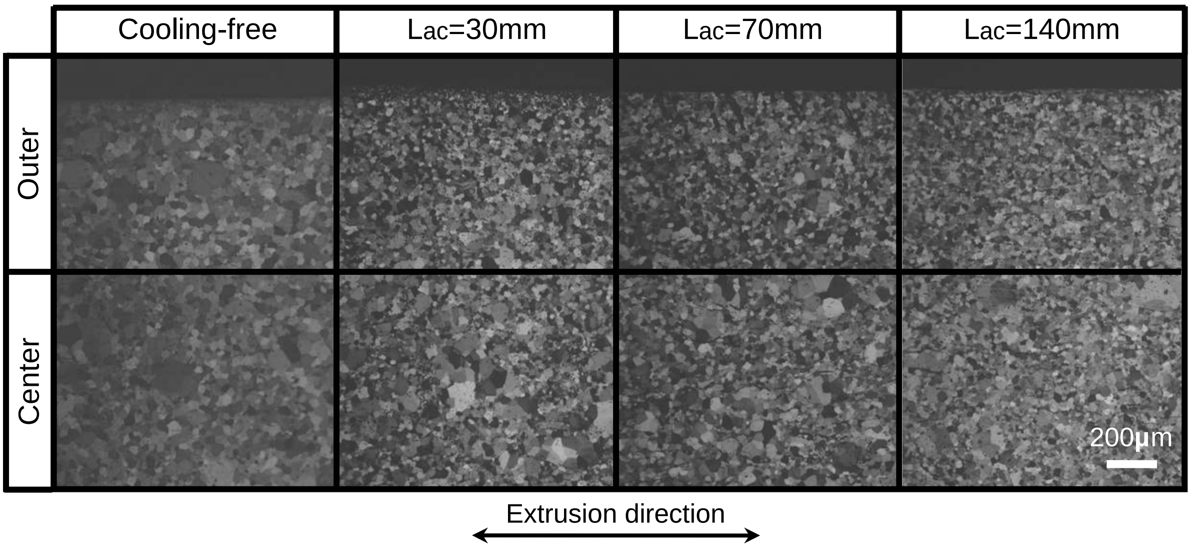

Figure 5: Optical microstructures of the longitudinal sections of the bars corresponding to Figure 3.

The reason why the forced-air cooling did not affect the material temperatures during extrusion can be understood by an assumption that the coming out speeds of the bars from a die are higher than the thermal conduction rate through the bars as far as L_{ac} was at least larger than 30mm and the blowing air didn't' cool the die-outlet surface directly.

In contrast to the results of extrudability and optical microscopy above, there were large differences in the tensile properties in the as-extruded condition. Under the condition of T_e =803K and V_R =10mm/s, forced-air cooling treatments greatly improve both the ductility and tensile strength, as shown in Figure 6. Especially for L_{ac} =70mm, the obtained tensile properties are comparable with those obtained in hot-extrusion. This implies that there exists an optimum air blowing position to achieve the maximum improvement in tensile properties, because the elongation is reduced again at L_{ac} =140mm. If V_R became higher at the same T_e, the optimum air blowing position shifted to the lower L_{ac} =30mm (Figure 7(a)). In the case of both higher V_R and T_e in Figure 7(b), none of the L_{ac}s gives good improvements, especially tensile elongation. But when the V_{ac} was increased to a few times larger than 80*l*/min at L_{ac}=30mm, a considerable improvement in elongation has been achieved. These results of tensile tests suggest that the adequate combination of L_{ac} and V_{ac} should be selected at each extrusion condition of V_R and T_e so as to get the most improved tensile properties.

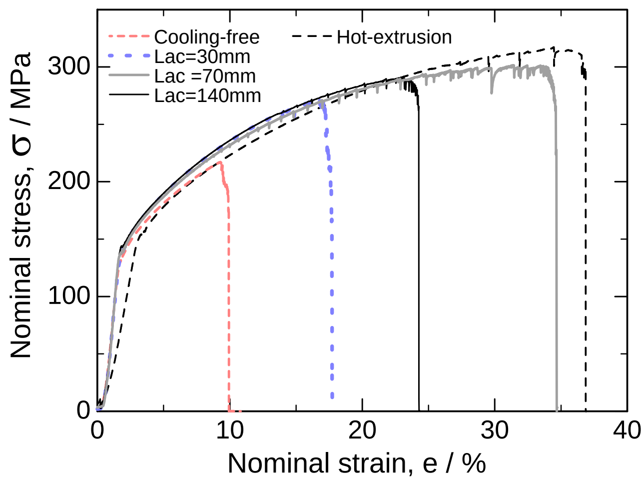

Figure 6: Typical stress-strain curves of the bars extruded at T_e =803K and V_R =10mm/s without and with forced-air cooling at various positions.

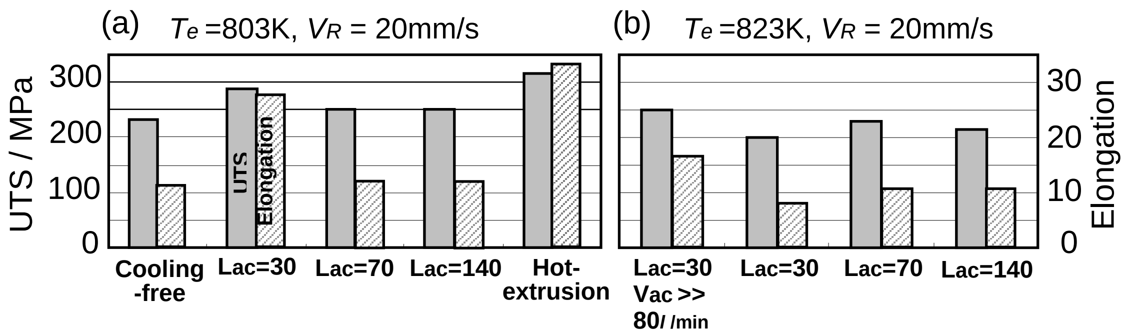

Figure 7: Effect of air blowing position on UTS and tensile elongation of the bars extruded at different extrusion conditions. (a) higher V_R , (b) both higher V_R and T_e .

Figure 8 shows a typical example that the fracture mode changes from an intergranular to a transgranular type as the poor ductility was improved. In the low magnification images, the dark spots corresponding to the holes, exist on the fracture surfaces of specimens with a lower elongation. These holes may be derived from defects, such as thin gaps that originally existed partially inside the extruded bar and were bonded together along the grain boundaries. The stress concentration is easy to develop at such defects. In contrast to this, such defects were rarely observed inside the extruded bar of L_{ac} =70mm having the most improved tensile properties.

On the other hand, the tensile elongation of Al-10wt%Mg alloy sheet made by hot- and cold-rolling processes decreased considerably accompanying the intergarnular fracture at somewhat progressed stages of aging due to the preferential precipitation of β phase at grain boundaries, despite no increase in proof stress [9]. Thus, the regions along grain boundaries inside the extruded bar without cooling may become weak because of a slight progress of precipitation resulting from the lower cooling rate. After solution treatment, in fact, the elongation recovered up to near 20%. Consequently, suppression of the defects along the grain boundaries and the progress of aging seem to lead to the improved tensile property at as-extruded condition. However, how the defects were generated and how they were suppressed by the forced-air cooling and the reason why an optimum L_{ac} existed are not clear at present.

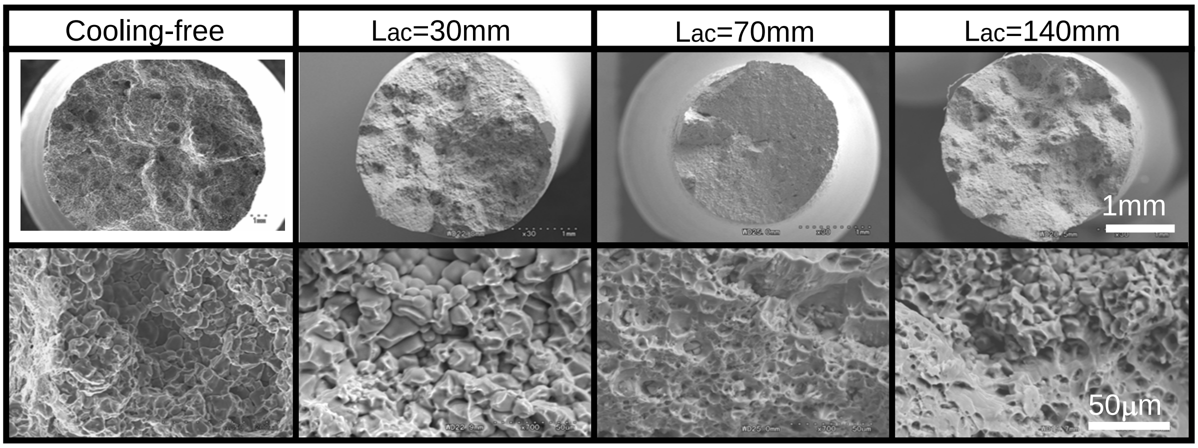

Figure 8: Fractographs of the bars extruded at T_e =803K and V_R =10mm/s without and with forced-air cooling at various positions.

If the liquids exist along some grain boundaries within the extruded bar just after passing through the die, and also if the cooling rate from such semi-solid state is slow (cooling-free and/or longer L_{ac}), cavities may form along thosegrain boundaries, similar to volumetric shrinkage during solidification. As to the existence of an optimum L_{ac} and effect of V_{ac}, quantitative assessment should be conducted by taking heat-flow into account. This is the next stage of this investigation.

4. Summary

When the forced-air cooling treatments were used during semi-solid extrusion at higher speeds of an Al-10wt%Mg alloy billet with a non-dendritic globular structure, every extruded bar had sound surfaces in spite of the various L_{ac}s. Clear difference in both extrusion force and grain structure between all bars existed scarcely. In contrast to these, the tensile properties became better and the most improved tensile property comparing with that for the hot-extrusion could be got at L_{ac} =70mm, T_e =803K and V_R =10mm/s. With increased elongation obtained, the fracture mode changed from intergranular to transgranular type.

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