

Effect of Temperature on Surface Cracking Defects in AA7075 Hot Extrusion

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Keywords: hot extrusion, 7075 aluminum alloy, cooling, tearing

Abstract. Aluminum alloys in the 7xxx series are high-strength alloys that are used in a wide variety of products in the transportation equipment and aerospace fields to reduce weight. In particular, the A7075 alloy has the highest strength and is expected to find further applications in a wide range of fields such as aircraft parts and sporting goods. However, low productivity is a problem due to its high deformation resistance, tendency to produce surface defects called tearing on the product surface, and short tool life. Tearing tends to occur under high temperature and high speed conditions, and is thought to be caused by local melting of Zn, an additive element, due to heat generation in processing. In this study, to improve the productivity of A7075 alloy, the profile was cooled during extrusion to prevent recrystallization of extrudate surface grains due to processing heat and to prevent processing heat during forming. In order to investigate the cooling effect, hot extrusion simulation was conducted. The cooling effect successfully suppressed the occurrence of tearing. These results indicate that cooling the extrudate during forming reduces the effect of heat generation during forming and prevents recrystallization of the extrudate surface grains and local melting of Zn.

Introduction

The 7000 series aluminum alloy is a high strength alloy to be used in a wide variety of products for the purpose of weight reduction in the transportation equipment and aerospace fields. The advantages of 7000 series aluminum alloys are high strength, excellent corrosion resistance, good electrical and thermal conductivity. Their strength can be improved by heat treatment [1]. Among the 7000 series aluminum alloys, the A7075 alloy has the highest strength to be further applied in a wide range of light-weight applications such as aircraft parts and sporting goods. For aluminum alloys manufacturing by hot extrusion, billet is pressed through an opening die obtaining a profile. A cross-sectional shape of profile with surface finish can be obtained by one deformation. Productivity and extrusion rate in hot extrusion processing are high, therefore it has been often used for aluminum alloys manufacturing [2]. However, extrusion productivity of the A7075 alloy is the lowest due to crack happen on extruded material surface during hot extrusion, especially at high speed and high temperature conditions. Crack defect is called tearing. In addition, since A7075 alloy has high deformation resistance and flow stress, then the extrusion rate is limited in the range from 0.8 to 2.0 m/min [3]. It has been reported by the authors of the present work that tearing is more likely to occur under high temperature and high velocity conditions [4]. In addition, local melting of intermetallic compounds including magnesium (Mg) and zinc (Zn) at high temperatures and segregation of these intermetallic compounds due to an increase in the recrystallization layer caused by processing heat were considered to cause tearing. In this paper, we focus on the product temperature to suppress the process heat generation during forming. In addition, hot extrusion

simulation was conducted to investigate the cooling effect. From the experiment and simulation, the effect of product temperature on the tearing behavior was investigated.

Experimental Method

In this experiment, A7075 alloy was used in hot extrusion. **Table 1** shows the composition of alloy. Billets were prepared by turning from a commercial cast alloy. The billets have a diameter of 41.5 mm and a length of 120 mm. **Figure 1** shows the 2000kN (200 tons) horizontal hydraulic oil press machine. The machine was used for hot extrusion experiment. The cartridge heaters and thermocouples are installed in a container. Temperature and ram speed can be controlled via controller. The extrusion load profile during hot extrusion was measured by a pressure sensor which is attached in the hydraulic controller. Ram stroke was measured by a laser displacement meter. These data was recorded via computer connecting.

Table 1 Chemical composition of A7075 (mass%).

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Zr	Ti	Al
A7075	0.08	0.21	1.78	0.05	2.46	0.19	5.61	-	0.01	Bal.

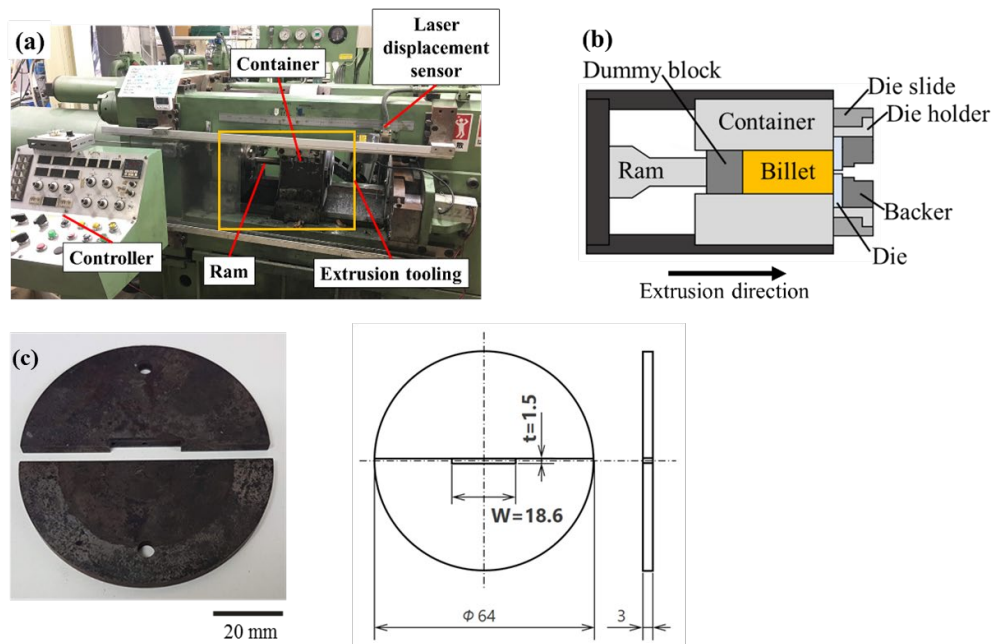


Fig. 1 (a) The 200-ton horizontal hydraulic oil press machine, (b) extrusion tooling, © shape of die.

The shape of die bearing part was a length of 18.6 mm and a width of 1.5 mm as shown in Fig. 1 (c). Bearing length was 3 mm. Extrusion ratio in this experiment was 49. The die was made of the SKD61 steel (HRC48). Die surface was treated by nitriding. In experimental conditions, billet temperature was 450 °C. Ram speed was 2.0 mm/s. Prior to extrusion, the billets and die were heated and held at the setting extrusion temperature for 2.5 h. **Table 2** shows the hot extrusion conditions in this experiment. The cooling method for the hot extrusion experiment is shown in **Fig. 2**. First, the extrudate was headed at a ram speed of 0.5 mm/s until the initial stroke of 15 mm. The extrudate was cooled to room temperature with ice. The temperature of the extrudate was monitored by a non-contact thermometer (TemPro 900, ADA INSTRUMENT). After that, extrusion experiments were carried out at a ram speed of 2.0 mm/s. The same process was used without cooling.

Table 2 Hot extrusion conditions.

Billet size (mm)	$\phi 41.5 \times 120$
Billet temperature (°C)	450
Die and Container temperature (°C)	450
Ram speed (mm/s)	1.5
Ram stroke (mm)	80
Extrusion ratio	49
Die Surface	Nitriding

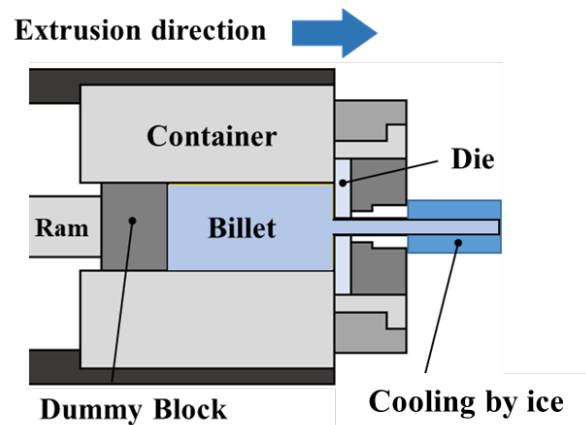
**Fig. 2** Cooling of the extrusion by ice (at head start).

Figure 3 shows surface appearance of the extruded material which was extruded at ram speed of 1.0 mm/s and billet temperature 450°C[4]. The total length of the extruded material after hot extrusion was 3600 mm. The surface of extruded material was observed at different position respected to distance from the tip head of extruded material including 600 mm (symbol; (I)), 1800 mm (symbol; (II)), and 3000 mm (symbol; (III)), denoted that the header, the middle, and the end, respectively. At 600 mm, cracks was not observed on extruded material surface. At 1800 mm, small cracks was observed whereas large crack was obviously seen at 3000 mm on the surface of the extruded material. Thereby, in this experiment, surface appearance at position of 3000 mm on extruded material was observed for classifying tearing

A digital microscope was utilized to observe tearing appearance on the surface of extruded material. The microstructures of extruded material and residual material were examined by using an Optical Microscope (OM), Scanning Electron Microscope (SEM).

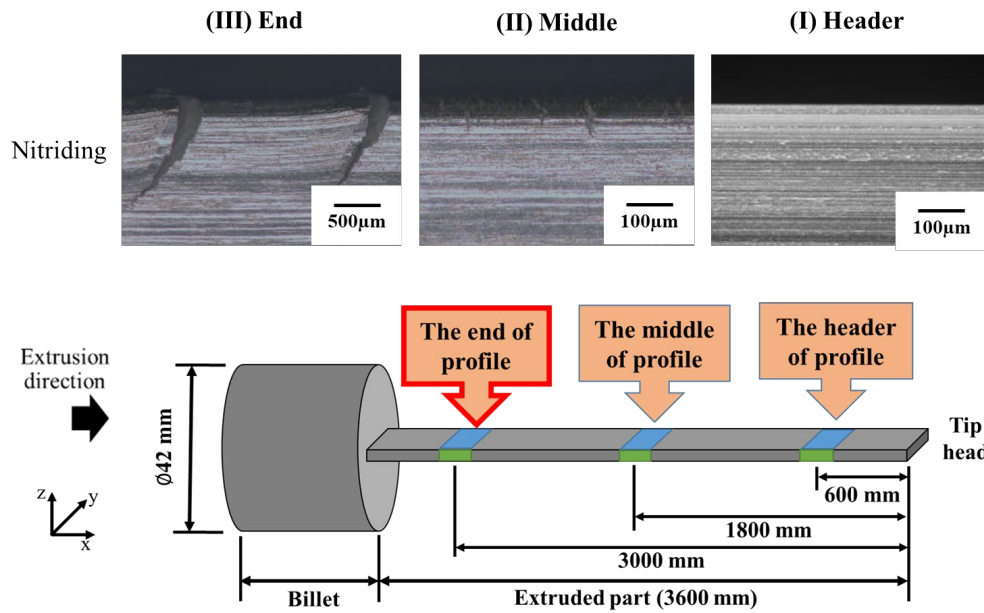


Fig. 3 Surface appearance of extruded material at difference distance from the tip head by z-axis view; (I) 600 mm, (II) 1800 mm, (III) 3000 mm. extruded by temperature 450 °C with extrusion speed of 1.0 mm/s[4].

The conditions of the hot extrusion simulation are shown in **Table 3**. DEFORM-3D was used as the simulation software, and the simulation method was lagrangian. The hot shear friction coefficient of AA7075 was derived from the friction test for hot metal forming from the authors' previous research and was set to $m=1.0$ [5]. In the hot extrusion simulation, the process heat generation was simulated assuming that the die was cooled down, and the die temperature was set to 0 and 470°C. The tearing is caused by the local melting of intermetallic compounds containing Zn and Mg [4]. Since the melting point of the intermetallic compound is around 470°C, the temperature of the simulation was set to 470°C. In addition, the temperature with cooling was set to 0°C in order to clearly show the effect of cooling with ice. The material model was referred to the material data of AA7075 in DEFORM. The initial number of elements in the billet was set to 100,000.

Table 3 Hot extrusion simulation conditions.

Billet size (mm)	$\phi 41.5 \times 120$
Billet temperature (°C)	470
Die and Container temperature (°C)	0, 470
Ram speed (mm/s)	1.5
Ram stroke (mm)	80
Extrusion ratio	49
Shear Friction Coefficient m	1.0 [5]
Heat Transfer Coefficient (Nmm/sec°C)	11
Initial Number of Elements (Billet)	100000

Results

Figure 4 shows the extrusion force vs. ram stroke curve at an extrusion temperature of 450°C and ram speed of 2.0 mm/s. In the extrusion force -ram stroke curve, ① is the head start, ② is the cooling, and ③ is the extrusion experiment. In ②, the extrusion force is zero because the experiment is stopped regardless of cooling. The maximum extrusion force was about 1700 kN (170 tons) in both cases with and without cooling. The cooling of the extrudate during extrusion did not affect the extrusion force.

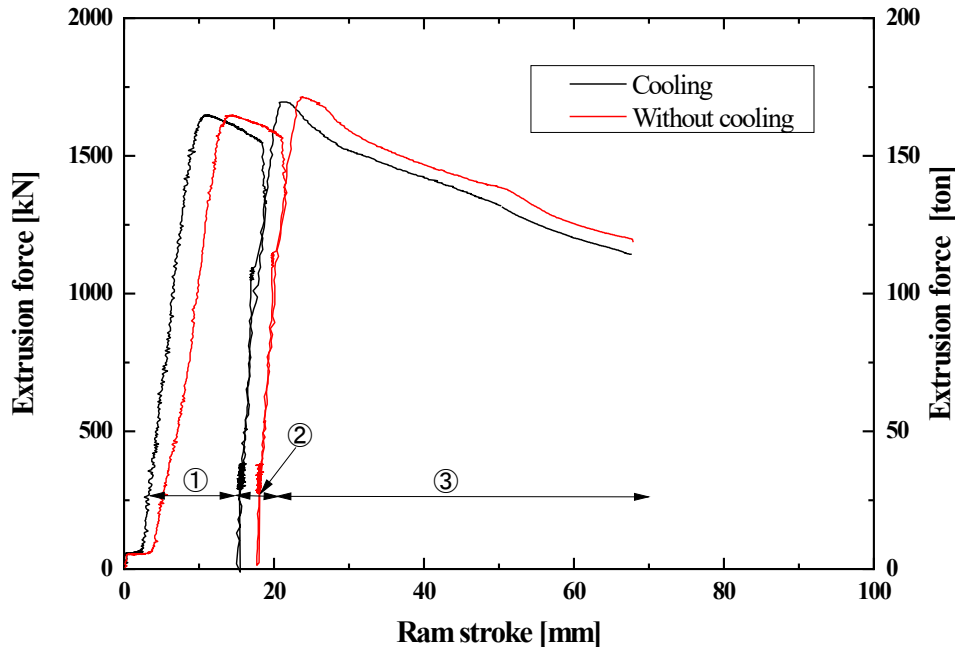


Fig. 4 Extrusion force-Ram stroke curve with cooling the extrusion and without cooling (Billet temperature 450°C, Ram speed 1.5mm/s, ① Extrusion for header, ② Cooling, ③ Hot extrusion test).

Figure 5 shows the tearing appearance of the extrudate at the extrusion temperature was 450°C and the ram speed was 2.0 mm/s without cooling. Tearing was observed at the header, the middle and the end of the extrudate. The tearing was irregularly scattered at the header but regular cracks at the end. The tearing is caused by the local melting of soluble intermetallic compounds containing Mg and Zn at grain boundaries due to the generated heat during extrusion, and the cracking propagates when strong tensile stress is applied to the extrudate during extrusion [4]. Similarly, in this experiment, during forming process, the generated heat is significant affect the material inducing tearing. In the cooled extrudate, tearing did not appear at the header and the middle. Tearing obviously appeared at the end of the extrudate. It can be thought that the extrudate was cooled into room temperature during cooling. Consequently, the local melting of soluble intermetallic compounds containing Mg and Zn is inhibited at grain boundaries. Since aluminum (Al) has a high thermal conductivity, the effect of cooling was observed between the first half of the extrudate and the middle of the extrudate, but tearing obviously appeared at the second half of extrudate due to the generated heat during processing and billet in the container was heated by heaters in side container.

The tearing depth of extrudate with and without cooling was about 1.50-300 μm , and 100-200 μm , respectively. The tearing occurs in the coarsened recrystallized microstructure layer at the edge of extrudate due to the heat generated during processing, which leads to crack propagation [4-5]. The cooling of the extrudate also inhibited the coarsening of the crystalline microstructure at the extrudate edge, which is thought to have reduced the tearing depth.

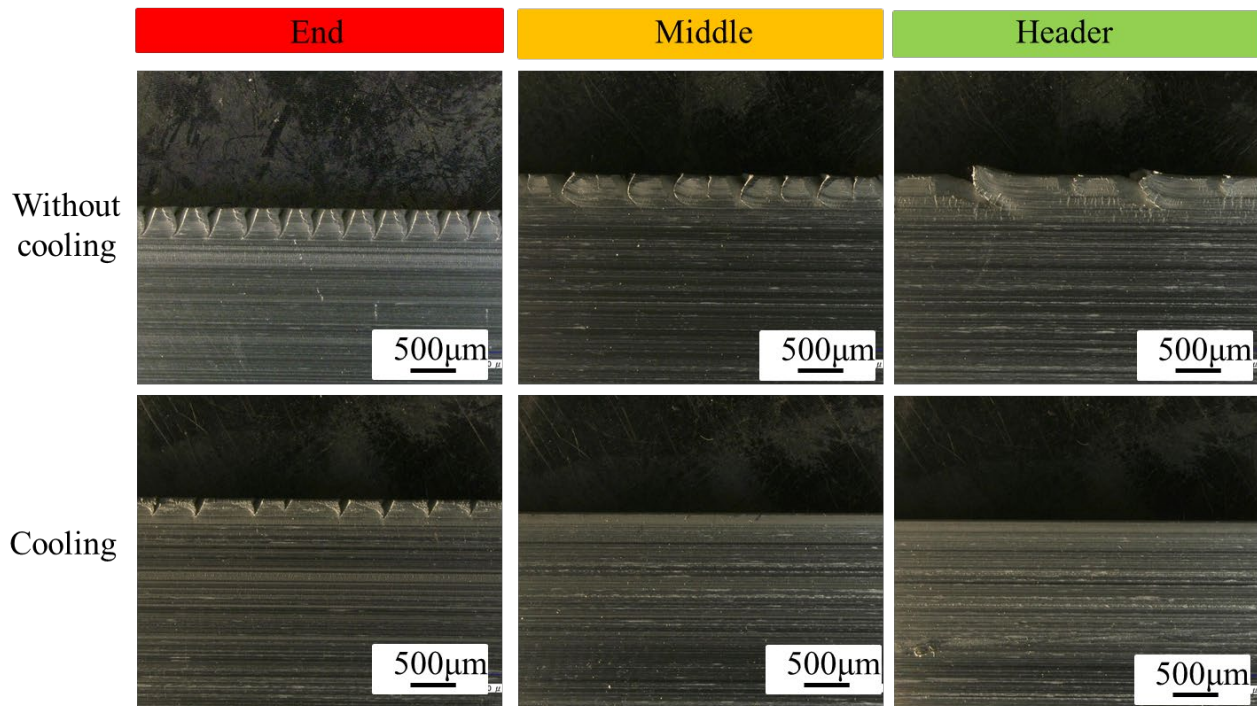


Fig. 5 Tearing appearance of the extrusion in header (Extrusion length 600mm), middle (Extrusion length 1800mm) and end (Extrusion length 3000mm) (Billet temperature 450°C, Ram speed 1.5mm/s).

In the hot extrusion experiment, the cooling of the extrudate at the time of head-off was performed, and the suppression effect on the tearing behavior was confirmed. In the hot extrusion simulation, the die and container were cooled and the heat generated during processing was observed because the material data such as deformation characteristics changed when the billet was brought to room temperature. **Figure 6** shows the temperature distribution of the extrudate in the hot extrusion simulation with the billet temperature of 470°C and the die temperatures of 0 and 470°C. The temperature of the extrudate at the die temperature of 0°C is about 480-500°C due to the process heat generation. At a die temperature of 470°C, the extrudate temperature is more than 530°C. The lower die temperature can suppress the process heat generation. No significant change was observed in the temperature distribution of the extrudate at the die temperature of 0°C. No change in the temperature distribution near the forming area was observed for the extrudate inside the container. On the other hand, at a die temperature of 470°C, the temperature range of 500-515°C near the forming section was expanded. It is considered that the increase of heat generation in the forming zone affects the temperature rise of the extrudate, and cooling in the forming zone leads to the decrease of heat generation.

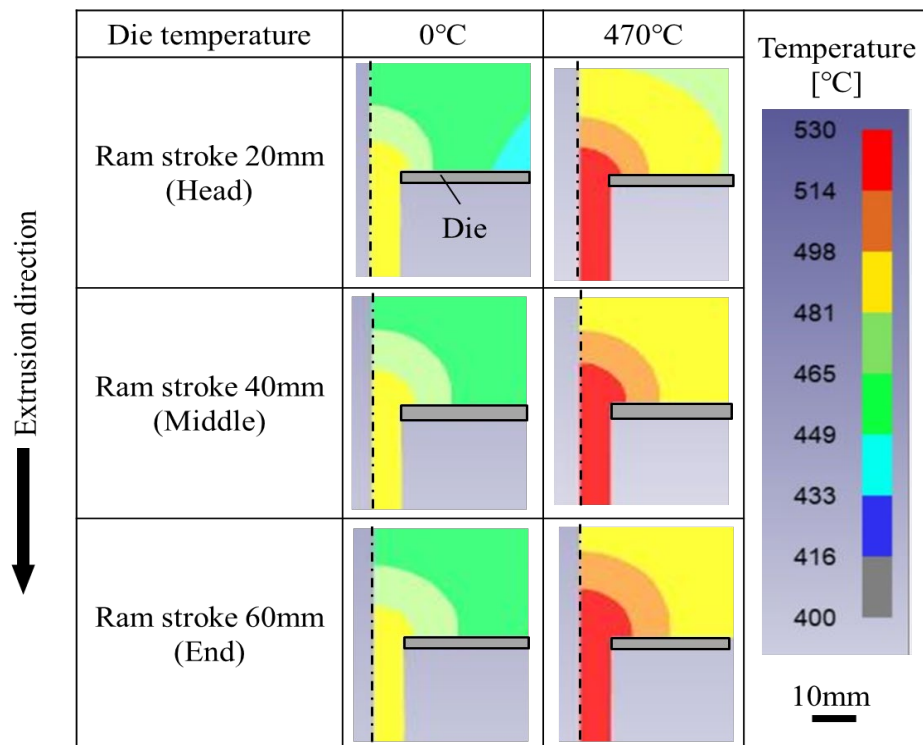


Fig. 6 Temperature distribution analysis by hot extrusion simulation (Billet temperature 470°C, Die temperature 0, 470°C, Ram speed 1.5mm/s).

As the obtained results from hot extrusion experiments and simulations, it can be seen that cooling system can reduce temperature at die and suppress the process heat generated on the extrudate. In addition, it was shown that the reduction of work heating leads to the reduction of tearing.

As a future research plan, microstructure observation of extrudates will be conducted to investigate the relationship between work heating and tearing. We will also investigate the relationship between the cooling time and tearing appearance, and realize the hot extrusion of AA7075 under high temperature and high speed conditions to develop the cooling system.

Summary

- The hot extrusion force did not change depending on whether cooling or not.
- At with cooling condition, tearing did not clearly appear at the until the middle of extrusion. In the end of extrusion, tearing obviously appeared on the extrudate due to heat generation, but the tearing depth was smaller comparing to condition of without cooling.
- In the simulation of hot extrusion with die cooling, the process heat generation in the forming part was reduced by cooling system.

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