

# Heat treatment conditions for forming AA6022 aluminum sheet in a forming process with intermediate heat treatment

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**Abstract.** The series of processes of pre-forming, heat treatment and forming for AA5182-O is known as one of forming process. However, it is possible that the appropriate intermediate heat temperature is different from that of AA5182-O when the process is applied to 6000 series aluminum alloy because it is age-hardening material. In this study, we examined the appropriate intermediate heat treatment temperature to improve the total elongation when the process was applied to AA6022-T4. The test was performed in the following procedure, preliminary tensile test, intermediate heat treatment, and tensile test. First, test specimens were subjected to a defined strain value. Next, test specimens were heat treated at several target temperatures as an intermediate heat treatment. The test specimen was removed from the furnace as soon as reaching the target temperature, and water-cooled immediately. Finally, tensile test was performed up to rupture of the specimen. As a result of the experiments, appropriate intermediate heat temperature to improve the total elongation was clarified when the process is applied to AA6022-T4. The appropriate temperature was different from that of AA5182-O.

**Keywords:** Aluminum sheet; Sheet metal forming; Heat treatment; Automotive.

## 1 Introduction

There is growing interest in reducing burden on the environment. In the automotive industry, weight reduction of vehicle is promoted to reduce CO<sub>2</sub> emissions during driving. As a part of this effort, the material changes from mild steel to aluminum are considered [1, 2].

In addition, efforts have been made in recent years to improve the recyclability of automotive components [3-5]. 5000 series (Al-Mg) and 6000 series (Al-Mg-Si) aluminum alloys, which are often used in automobiles, have different additive element [6]. For this reason, sorting process is necessary for recycling. To eliminate the sorting process, all components should be made of 6000 series aluminum alloys. However, many components currently made of 5000 series aluminum alloys are difficult to form. Therefore, a process is needed to improve the formability of 6000 series aluminum alloys.

There are previous studies on improving the formability of 5000 series aluminum alloys by using intermediate heat treatment (IHT). This process consists of pre-forming, intermediate heat treatment, and main forming [6, 7]. The process is used in the manufacture of automobile components, and the hurdles to practical application are low [8, 9]. Applying this process to 6000 series aluminum alloys is expected to improve formability. However, because 6000 series aluminum

alloys are age-hardenable. The appropriate intermediate heat treatment temperature range is likely to be different from that of 5000 series aluminum alloys.

Therefore, in this study, the effect of the IHT temperatures on the total elongation is examined by tensile test. In addition, the effect of the IHT on the yield stress after baked coating process is also examined. The electrical conductivity after the IHT is measured to examine the precipitation state. The microstructure is observed to examine the effect of the IHT on grain size.

## 2 Methods and procedures

The material used throughout this study was a 1.0 mm thick AA6022-T4 aluminum sheet. A yield stress was 150 MPa and a total elongation was 24.0% in true strain.

### 2.1 Tensile test conditions

In this study, an AUTOGRAPH AG-10TA and an extensometer SIE-560 from Shimadzu Corporation were used for the tests. The specimens were pulled at room temperature in a direction of zero degrees relative to the rolling direction. Tests were performed with a crosshead displacement rate of 5 mm/minute. Each test condition was repeated twice to calculate the average value.

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The schematic diagram of the test flow is shown in Fig. 1. Tensile tests were performed in four different processes. Process 1 and Process 2 were simulated a forming process without IHT (i.e., a normal forming process). The total elongation was examined in Process 1. The yield stress after baked coating was examined in Process 2. Process 3 and Process 4 were simulated the process with IHT. The effect of IHT on the total elongation was examined in Process 3. The effect of IHT on yield stress after baked coating was examined in Process 4. The test procedures for each process were described below.

In Process 1, tensile test was performed according to ISO6892-1 [10]. Test piece type 3 was used for the test.

In Process 2, a test piece type 3 was subjected to approximately 2.0% in true strain. Furthermore, the heat treatment simulating baked coating (hereafter referred to as BC heat treatment) was performed at 170°C for 20 minutes using an air heating furnace. The test piece was air cooled to room temperature after BC heat treatment. Thereafter, tensile test was performed under the same conditions as in Process 1.

In process 3, the series of tests were performed with IHT temperature as a parameter. First, preliminary tensile test was performed. The specimen shape was rectangular with 210 mm length (in the rolling direction) and 40 mm width. The specimens were pulled to approximately 9.2% in true plastic strain under room temperature with a gauge length of 50 mm. Next, the specimens were processed into test piece type 3. Then, test pieces type 3 were heat-treated at eight target temperatures of 100, 150, 200, 250, 350, 400, 450 and 500°C as an IHT. The IHT conditions are shown in Table 1. An oil bath was used when the IHT temperature was below 200°C, and a salt bath furnace was used when the heat treatment temperature was above 250°C. The temperature of each test piece during IHT was measured by K-type thermocouples and data loggers. For each IHT temperatures, the heating time of the test piece was below 10 seconds. The test piece was removed from the furnace as soon as reaching the target temperature, and water-cooled immediately. Finally, tensile test was performed under the same conditions as in Process 1.

In Process 4, the test was performed in the same procedure as in Process 3 up to water cooling. In Process 4, however, the IHT temperatures were 150°C, 400°C, and 450°C. After water cooling, the test was performed in the same procedure as in Process 2.

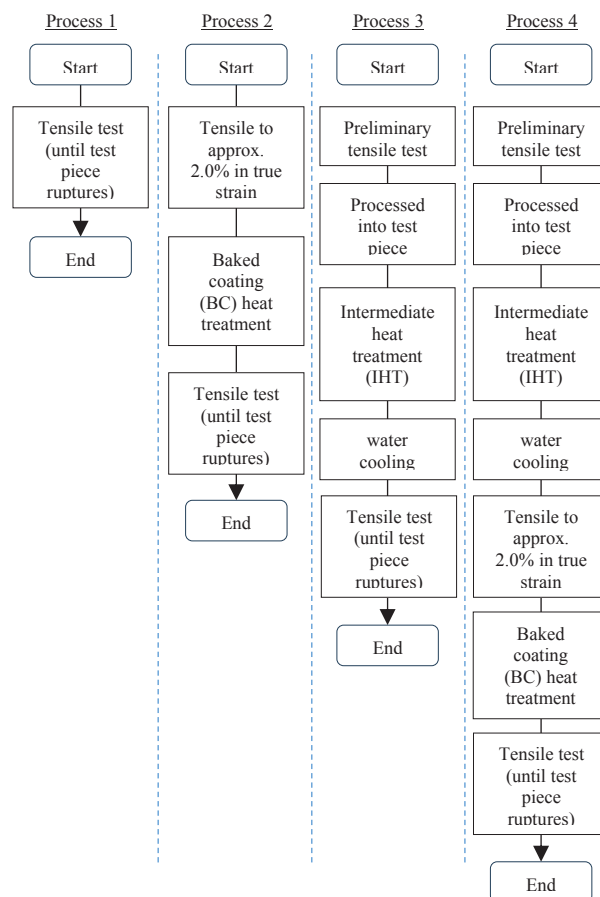


Fig. 1. Schematic diagram of test flow for each process.

Table 1. Intermediate heat treatment conditions.

Target intermediate heat treatment temperature [°C]	Type of a furnace	Set temperature of the furnace [°C]	Heated time reached to target temperature (measured value) [sec.]
100	oil bath	130	8.0
150	oil bath	180	6.7
200	oil bath	220	4.7
250	salt bath	285	6.2
350	salt bath	390	3.2
400	salt bath	430	4.6
450	salt bath	480	5.4
500	salt bath	540	7.1

## 2.2 Method of deriving elongation and yield stress

In Processes 1 and 3, elongation was examined as the formability. The position of fracture was determined

from the load-displacement relationship obtained during the tensile test, and the total extension at fracture ( $A_t$ ) was determined [10]. The schematic image of total elongation is shown in Fig. 2. In Process 3, the total elongation, which is the sum of the  $A_t$  from the tensile test and the true plastic strain from the preliminary tensile test, was examined.

In Process 2 and 4, the yield stress was examined. the proof strength at 0.2% plastic strain ( $R_{p0.2}$ ) was obtained from the engineering stress – engineering strain curb [10]. The  $R_{p0.2}$  was defined as the yield stress in this study.

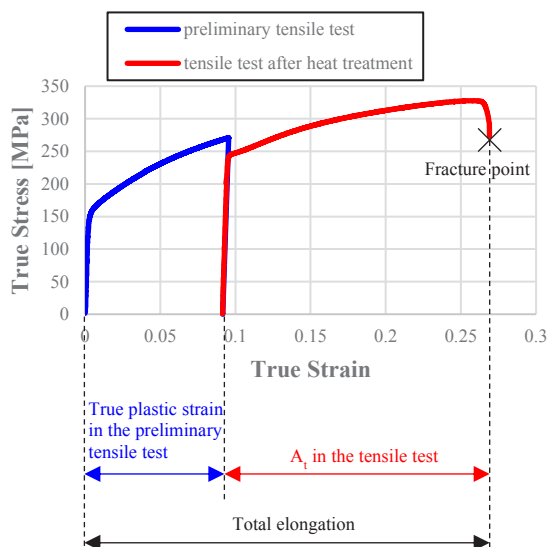


Fig. 2. Schematic image of total elongation.

### 2.3 Electrical conductivity measurement conditions

Electrical conductivity measurement is sometimes used as a simple method to examine precipitation behaviour [11]. Changes in electrical conductivity were measured to examine the effect of IHT on precipitation state. The specimens were AA6022-T4 material before testing (hereinafter referred to as “raw material” in this paper) and specimens after water cooling in Process 3. SIGMATEST manufactured by FOERSTER JAPAN LIMITED was used for the measurements.

### 2.4 Microstructure measurement conditions

The effect of IHT on microstructure was examined. The microstructure of the raw material and specimens heat-treated at 100, 150, 200, 450 and 500°C in Process 3 was observed. For raw material, specimens for observation were cut from a sheet. For heat-treated specimens, they were cut from the center of the test pieces. The cut specimens were resin-filled. The microstructure parallel to the rolling direction was observed in all conditions. The specimen surface was ground with Silicon Carbide Foil to #2000, furthermore polished with diamond paste (9 micro meter and 3 micro meter) until the specimen

surface was mirror-like. In addition, electrolytic etching was performed using the Barker method (4% HBF<sub>4</sub>) at 0.1A, 30V for approximately 60 seconds. The microstructure of the specimens after electric etching was observed using a Nikon ECLIPSE MA200 microscope with a polarizing filter.

## 3 Results and discussion

### 3.1 Effect of the intermediate heat treatment on formability improvement

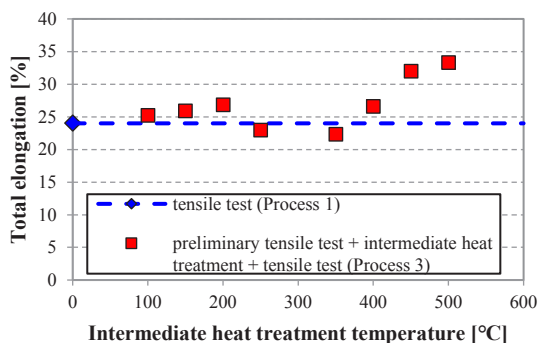
#### 3.1.1 Tensile test results

The tensile test results are shown in Table 2. The graph comparing the average value of total elongation with IHT temperature is shown in Fig. 3. The total elongation was improved under the conditions of IHT at temperatures between 100°C and 200°C or above 400°C. In contrast, the total elongation decreased in the range of IHT temperatures between 250°C and 350°C.

The appropriate IHT temperature range for AA5182-O is between 250 and 350°C [9]. In contrast, in the case of AA6022-T4 aluminum sheet, it was found that this temperature range had a negative effect on the total elongation.

Table 2. Tensile test results.

Process	Intermediate heat treatment temperature [°C]	n	True plastic strain in Preliminary tensile test [%]	$A_t$ in tensile test (true value) [%]	Total Elongation [%]	
					-	average
1	-	1	-	24.55	24.6	24.0
		2	-	23.54	23.5	
3	100	1	9.18	15.84	25.0	25.2
		2	9.17	16.24	25.4	
	150	1	9.19	16.43	25.6	25.9
		2	9.20	16.99	26.2	
	200	1	9.17	17.75	26.9	26.9
		2	9.18	17.62	26.8	
	250	1	9.20	14.15	23.3	23.0
		2	9.19	13.43	22.6	
	350	1	9.23	13.46	22.7	22.3
		2	9.21	12.76	22.0	
	400	1	9.23	16.89	26.1	26.6
		2	9.22	17.90	27.1	
	450	1	9.22	24.40	33.6	32.0
		2	9.24	21.14	30.4	
	500	1	9.19	25.05	34.2	33.3
		2	9.17	23.28	32.4	

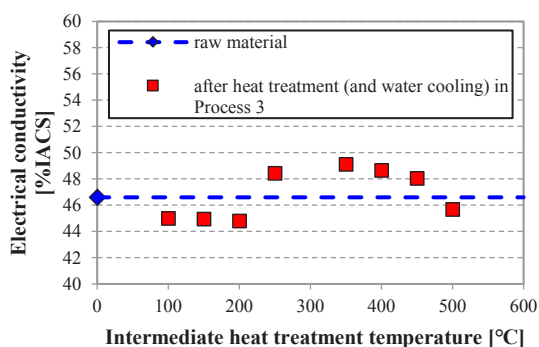


**Fig. 3.** Comparison of the intermediate heat treatment temperature and the total elongation.

### 3.1.2 Results of electrical conductivity measurement

In 6000 series aluminum alloys, second phase particles precipitate by heat treatment. According to previous research, the precipitation sequence is supersaturated solid solution  $\rightarrow$  nanocluster  $\rightarrow$   $\beta''$   $\rightarrow$   $\beta'$   $\rightarrow$   $\beta$  [12]. It is also known that the precipitation of second phase particles reduces elongation [13].

In this study, the precipitation state was examined from the results of electrical conductivity measurement. The relationship between IHT temperatures and electrical conductivities is shown in Fig. 4. It is known that the cluster formation increases electrical resistance (i.e., decreases electrical conductivity) [14]. When the IHT was performed at 100, 150, and 200 °C, the electrical conductivity was lower than that of the raw material. Thus, this is presumably the result of cluster formation caused by IHT. In addition, the electrical conductivity increases when second phase particles precipitate [15]. As shown in Fig. 4, the electrical conductivity was higher than that of the raw material at 250, 350, 400, and 450 °C for IHT. Therefore, it is assumed that second phase particles precipitate in this temperature range. When the IHT temperature was 500 °C, the electrical conductivity was almost the same as that of the raw material. Previous research has shown that the  $\beta$  phase dissolves in this temperature range [12]. Thus, it is assumed that second phase particles did not precipitate.



**Fig. 4.** Comparison of intermediate heat treatment temperature and electrical conductivity.

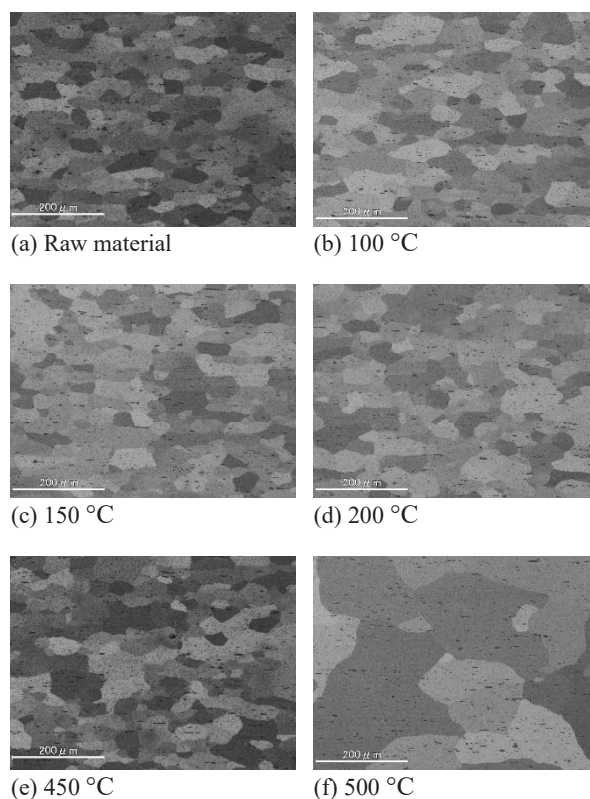
### 3.1.3 Discussion on the effect of the intermediate heat treatment on the total elongation

Typically, when a work-hardened material is subjected to a heat treatment, the accumulated dislocations in the work-hardened material are reduced [16]. This recovery effect improves the total elongation [6].

On the other hand, in the case of AA6022-T4, second phase particles precipitated at 250, 350, 400, and 450 °C for IHT. The precipitation of second phase particles reduces the elongation [13]. Therefore, we conclude that the decrease in elongation due to the precipitation of second phase particles offset the increase in elongation due to the recovery effect.

### 3.2 Effect of the intermediate heat treatment on grain size

Microstructural images of raw material and specimens after IHT (and water cooling) in Process 3 are shown in Fig. 5. The longitudinal direction is the thickness direction of the sheet and the horizontal direction is the rolling direction of the sheet (i.e., tensile direction). The grain size was not changed under conditions of IHT temperature below 450 °C. In contrast, grain growth occurred at an IHT temperature of 500 °C, resulting in coarse grains. It is known that orange peel after forming caused by coarse grain [17]. Thus, the IHT temperature should be below 450 °C.



**Fig. 5.** Microstructures of raw material and the materials after intermediate heat treatment (and water cooling) in Process 3 (the vertical direction of the image is in the thickness direction and the horizontal direction is in the rolling direction).

### 3.3 Effect of the intermediate heat treatment on the yield stress after BC heat treatment

The relationship between yield stress and IHT temperature is shown in Fig. 6. Only the IHT temperature range over which the total elongation improved was examined. In the test process without IHT (Process 2), the yield stress after BC heat treatment was 221 MPa. The yield stress after BC heat treatment in the test process with IHT (Process 4) is compared with this value. When IHT was performed at 150°C, the yield stress after BC heat treatment was 269 MPa, and it was higher than that of Process 2. In contrast, when IHT was performed at 400°C, the yield stress after BC heat treatment was 166 MPa. When IHT was performed at 450°C, the yield stress after BC heat treatment was 155 MPa. For both IHT temperatures (i.e. 400°C and 450°C), the yield stress after BC heat treatment was below that of Process 2.

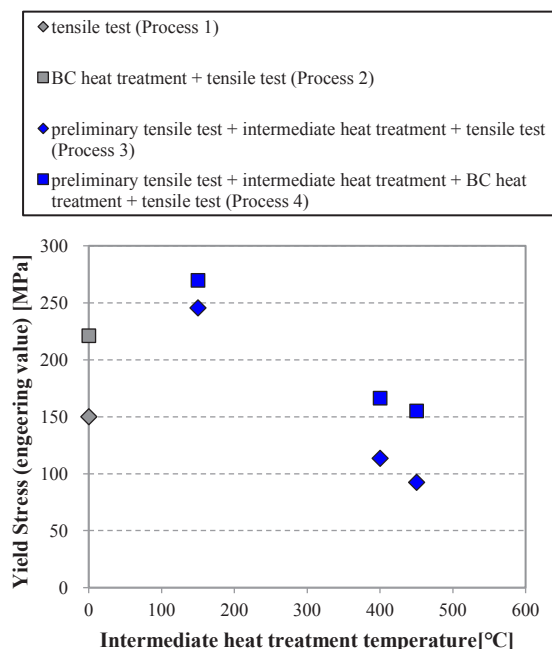


Fig. 6. Comparison of intermediate heat treatment temperature and yield stress in engineering value.

## 4 Conclusions

The work has shown test processes to examine the effects of intermediate heat treatment on 6000 series aluminum alloys. For AA6022-T4 aluminum sheet, appropriate intermediate heat treatment temperature ranges have been between 100 and 200°C, as well as between 400 and 450°C. In particular, when the intermediate heat treatment temperature is above 400°C, the total elongation is improved significantly. On the other hand, the yield stress after baked coating is lower than that of raw material when the intermediate heat treatment temperature is 400°C and 450°C. Therefore, the intermediate heat treatment temperature range

should be selected according to whether the yield stress reduction after baked coating is acceptable.

Further investigations are needed to show the effect of the strain amount subjected in preliminary tensile test

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