Study on pre-stretching - contact heating - artificial aging process of 7075 aluminum alloy

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Due to the low elongation of aluminum alloys at room temperature, which often leads to cracking during forming, hot stamping is commonly used to improve the formability of aluminum alloys. However, in traditional hot stamping processes, the solid solution treatment time is excessively long and cannot match the subsequent forming steps. Therefore, this study adopts a contact heating method that can shorten the solid solution time to within 30 seconds and enhance the material properties to a certain extent. To further enhance the strength of aluminum alloys, this paper proposes a pre-stretching - contact heating - artificial aging process, and investigates the effects of deformation and contact heating processes on the mechanical properties and microstructure of aluminum alloys. The results show that the aluminum alloy treated with contact heating can achieve a strength of 568.46 MPa after being held at 120°C for 18 hours, exceeding the performance of the T6 state. Moreover, as the deformation increases, the strength of the aluminum alloy continues to improve, reaching a maximum of 591.42 MPa after 24 hours of aging treatment at a deformation of 10%.

Keywords: 7075 Aluminum Alloy; Contact Heating; Pre-stretching; Artificial Aging.

1. Introduction

With the rapid development of modern industrial technology, aluminum alloys have been extensively utilized in the automotive lightweighting sector due to their desirable properties such as lightweight, high strength, and corrosion resistance[1-3]. Among these, 7075 aluminum alloy, belonging to the Al-Zn-Mg-Cu series of superhard aluminum alloys, stands out as a high-strength alloy with remarkable comprehensive performance.

High-strength aluminum alloys exhibit low ductility at room temperature, resulting in difficulties in precisely controlling springback during the forming process and a tendency to crack, thereby affecting their overall formability [4]. To address these challenges, the hot stamping process for aluminum alloys has been developed [5, 6], aiming to significantly enhance the formability of the material while improving its mechanical properties and surface quality, enabling the production of parts with complex structures. Prior to forming, aluminum alloys generally require solution heat treatment [7, 8]. Currently, the solution heat treatment for 7075 aluminum alloy sheets commonly utilizes a heating furnace, taking approximately 30 minutes. However, the subsequent forming and quenching processes only require approximately 20 seconds. The excessively long duration of the preliminary solution heat treatment fails to synchronize with the forming process, significantly restricting the production application of this technology [9].

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In this study, a contact heating method is employed [10, 11], which involves directly heating the sheet through upper and lower contact bodies, enabling the completion of the solution process within 30 seconds. This approach not only boasts high heat transfer efficiency but also offers convenient operation, enhancing production efficiency and versatility. To further enhance the performance of aluminum alloys, deformation is an effective method. Crystal defects introduced by pre-deformation, such as vacancies and dislocations, have a significant impact on the aging precipitation process of alloys. Therefore, this study utilizes pre-stretching to pre-deform the material, combines pre-stretching deformation with the contact heating process, and thoroughly investigates the specific effects of pre-deformation and contact heating on the properties of 7075 aluminum alloy.

2. Experimental Materials and Procedures

2.1. *Experimental Materials*

The experimental materials used in this study are all T6-tempered 7075 aluminum alloy sheets with a thickness of 2 mm. Their chemical compositions and mechanical properties are presented in Table 1 and Table 2, respectively.

Table 1 Chemical composition of aluminum alloy 7075-T6(wt.%)

Element	Zn	Mg	Cu	Fe	Si	Mn	Cr	Al
Wt%	5.2	2.3	1.5	0.13	0 .03	0.18	0.2	Bal

Table 2 Mechanical properties of aluminum alloy 7075-T6

	Tensile strength (MPa)	Yield strength(MPa）	Elongation (%)
7075-T6	557.05	488.62	13.5

2.2. *Experimental Procedures*

Figure 1 illustrates the schematic diagram of the aluminum alloy pre-stretching-contact heating-artificial aging process. Firstly, the T6-tempered sheets were processed into the pre-stretching specimen shape as shown in Fig. 2. Different deformation amounts (0, 2%, 4%, 6%, 8%, 10%) were applied using an Instron 3382 tensile testing machine. Subsequently, the pre-stretched aluminum alloy sheets were placed between the upper and lower contact bodies of a contact heating device that had been preheated to 480°C. The holding time was set to 30 seconds. Immediately after the solution heat treatment, the sheets were water-quenched to ensure supersaturated solid solution. Following this, artificial aging treatments were performed at 120°C for different durations (12h, 18h, 24h). Tensile specimens were cut from the center of the aluminum alloy sheets after various process treatments, and mechanical properties were tested to investigate the effects of different deformation amounts and contact heating processes on the aluminum alloy.

The contact heating experimental setup, as depicted in Fig. 3, primarily consists of three parts: upper and lower flat dies, a cold die, and a hot die. By combining the upper and lower flat dies with a U-shaped mold device, an integrated process of contact heating and hot stamping can be achieved. In this study, the contact heating flat die setup was primarily utilized. The pre-stretched aluminum alloy was placed between the upper and lower flat dies, and the dies were closed through the movement of the press's slider, thereby completing the solution heat treatment process of the aluminum alloy. This process can be controlled within approximately 30 seconds, significantly reducing the solution time.

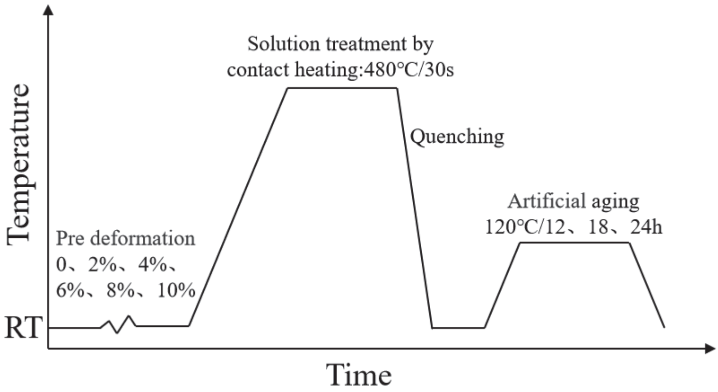

Fig. 1. The pre-stretching-contact heating-artificial aging process

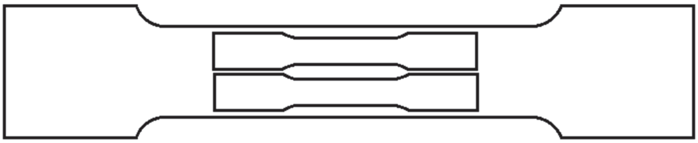

Fig. 2. Pre-stretched specimen shape

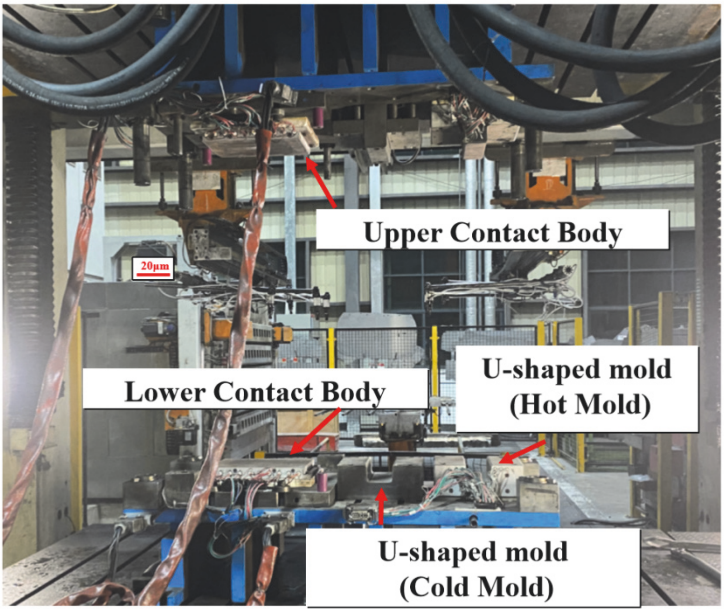

Fig. 3. Contact heating device

2.3. *Mechanical Property Testing*

Figure 4 demonstrates the specific dimensional parameters of the aluminum alloy tensile specimens, with an overall length of 100 mm, a thickness of 2 mm, and a width of 10 mm. Tensile tests were conducted on the specimens using an Instron 3382 tensile testing machine, with a tensile speed of 3 mm/min and a 30 mm extensometer selected for the experiment.

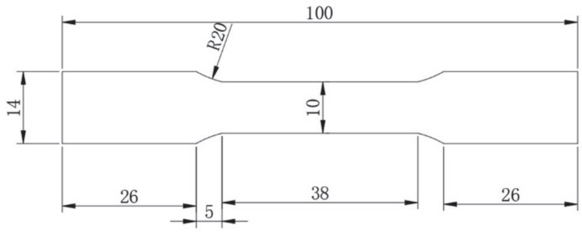

Fig. 4. Tensile specimen size of test aluminum alloy

2.4. *Metallographic Observation*

To investigate the microstructure of the aluminum alloy, an optical microscope model DS-300 was employed. Firstly, the aluminum alloy material was cut into small pieces using wire cutting technology for subsequent embedding processing. Then, the material was ground with water using sandpaper ranging from 200# to 5000#. Following this, polishing was carried out until the surface exhibited a scratch-free condition. Subsequently, the material was etched using Keller's reagent, and finally, the metallographic structure of the aluminum alloy was observed.

3. Experimental Results and Analysis

3.1. *Impact of Contact Heating Process on Aluminum Alloy Properties*

To investigate the effect of contact heating process on the properties of aluminum alloy, the aluminum alloy was subjected to contact heating treatment at 480°C for 30 seconds, followed by artificial aging treatment at 120°C for different durations (12h, 18h, 24h). Tensile tests were conducted on materials processed under different conditions, and the corresponding stress-strain curves are shown in Fig. 5. For comparison with the furnace solid solution process, the aluminum alloy sheet was placed in a furnace for solid solution treatment at 480°C for 30 minutes, followed by artificial aging treatment at 120°C for 24h. Mechanical property tests were also performed, and the resulting stress-strain curves are also presented in Fig. 5. It can be observed from the figure that the performance of the specimens treated with contact heating is superior to that of the furnace-treated specimens. Among them, the aluminum alloy sheet aged at 120°C for 18 hours exhibits the most optimal mechanical properties, with slightly higher strength and elongation compared to 24h.

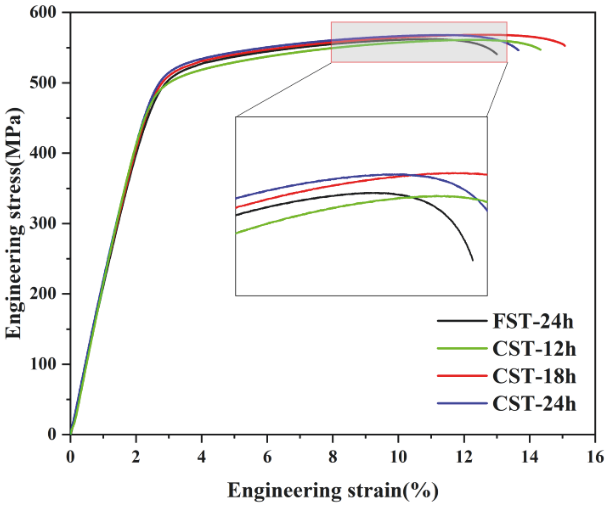

Fig. 5. Comparison of tensile curves between contact heating samples and furnace solid solution samples

After the contact heating treatment, the specific data results of the yield strength, tensile strength, and elongation of the aluminum alloy material are shown in Table 3. As can be observed from the graph, the strength and hardness of the samples treated with contact heating exhibit an increasing trend with the increase in aging time. The maximum strength is achieved at 18h, and the strength obtained at 24h is slightly reduced. The elongation remains relatively stable within the range of 13% to 15% with the extension of aging time. When the aluminum alloy undergoes artificial aging for 12h, its tensile strength is 561.18 MPa, and the yield strength is 486.02 MPa. When the aluminum alloy undergoes artificial aging for 18h, it achieves optimal performance, with a tensile strength of 568.46 MPa, a yield strength of 507.81 MPa, and an elongation of 15.08%. Compared to the sample processed with furnace solid solution treatment, its strength is significantly improved, and the elongation does not decrease. This indicates that the solid solution treatment of aluminum alloy through contact heating technology can significantly enhance the strength and optimize the properties of the material. This is mainly because contact heating allows the aluminum alloy material to be rapidly heated in a short period. This rapid heating process promotes the rapid dissolution of the second phase in the aluminum alloy matrix, thus increasing the supersaturation of the solid solution. In the subsequent artificial aging treatment stage, more second phases are precipitated, further enhancing the properties of the aluminum alloy material.

Table 3 Mechanical properties of contact heating samples varying with artificial aging time

Aging time（h）	Tensile strength(MPa)	Yield strength(MPa）	Elongation(%)
12	561.18	486.02	14.33
18	568.46	507.81	15.08
24	568.03	506.18	13.67

3.2. *Impact of Introducing Pre-deformation on Aluminum Alloy Properties*

The T6 state 7075 aluminum alloy was subjected to pre-tensile deformation at 2%, 4%, 6%, 8%, and 10%. The pre-deformed aluminum alloy sheets were then processed with a contact heating device for solid solution treatment at 480℃ for 30 seconds, followed by aging treatment at 120℃ for various durations (12h, 18h, 24h). The aim was to investigate the influence of the pre-tensile deformation-contact heating-artificial aging process on the mechanical properties of the aluminum alloy. Tensile tests were performed on aluminum alloy samples that underwent different pre-tensile deformation amounts, contact heating solid solution treatment, and artificial aging for varying durations. The trends in the yield strength, tensile strength, and elongation of the aluminum alloy material are shown in Fig. 6, with the T6 state properties serving as a comparison.

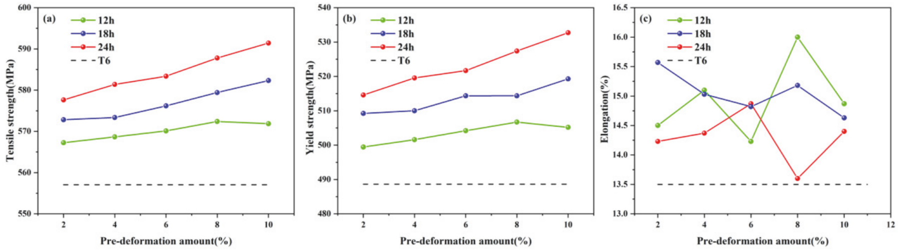

Fig. 6. Mechanical properties of pre-tensile-contact heating samples varying with artificial aging time: (a) tensile Strength; (b) yield Strength; (c) elongation.

As observed in Fig. 6, the strength of the pre-stretched specimens exhibited an upward trend with increasing deformation after contact heating and various aging durations, while the elongation remained relatively stable, fluctuating within the range of 13% to 16%. After undergoing 10% pre-stretching deformation, combined with contact heating and subsequent aging treatment at 120℃ for 24 hours, the aluminum alloy demonstrated the most superior performance, with a tensile strength of 591.42MPa, a yield strength of 532.71MPa, and an elongation of 14.4%. Compared to the T6 state, the tensile strength was increased by 34.37 MPa, and the yield strength was elevated by 44.09 MPa, without any compromise in elongation. This significant improvement in performance, compared to specimens without pre-deformation, suggests that applying pre-deformation to aluminum alloy specimens before contact heating solid solution treatment can effectively induce work hardening, thus notably enhancing the strength and overall performance of the material.

3.3. *Comparison between Contact Heating Process and Furnace Solutionizing Process*

To better compare the contact heating process with the furnace solid solution process, T6-state 7075 aluminum alloy specimens were subjected to pre-stretching treatments at 2%, 4%, 6%, 8%, and 10% deformation, followed by a solid solution treatment in a furnace at 480℃ for 30 minutes. Subsequently, the specimens underwent artificial aging at 120℃ for 24 hours. The resulting stress-strain curves are depicted in Fig. 7, and the specific performance data is presented in Table 5. When compared to the mechanical properties obtained from aluminum alloy specimens that underwent contact heating followed by 120°C/24h artificial aging, it is evident that the specimens treated with the furnace solid solution process consistently exhibited lower performance across different pre-stretching deformation levels. This result strongly demonstrates that aluminum alloy specimens processed with contact heating achieve a more thorough solid solution state, leading to a higher supersaturation level and subsequently more significant second-phase strengthening effects after aging precipitation.

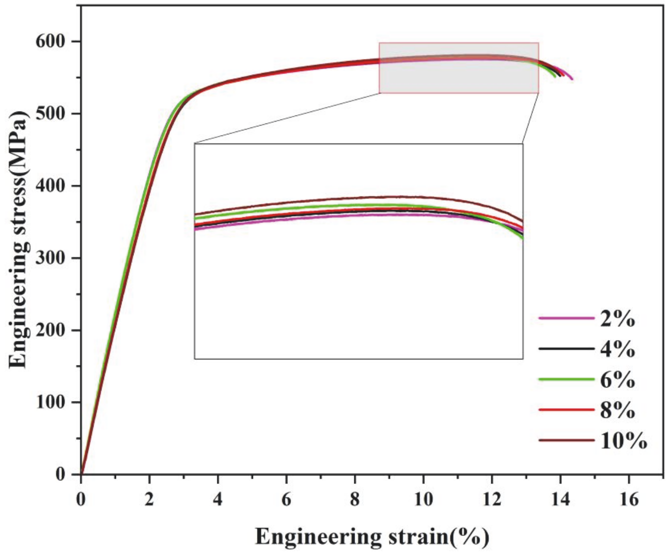

Fig. 7. Tensile curves of pre-stretched-furnace solution-treated samples with varying deformation amounts

Table 5 Mechanical properties data of pre-stretched-furnace solution-treated samples with varying deformation amounts.

Pre-deformation amount (%)	Tensile strength (MPa)	Yield strength(MPa）	Elongation (%)
2	575.33	517.39	14.35
4	576.57	523.35	14
6	578.5	519.69	13.85
8	577.35	519.65	14.1
10	581.09	528.96	13.95

3.4. *Effect of Pre-tensile Deformation-Contact Heating-Artificial Aging Process on Aluminum Alloy Structure*

To investigate the effect of the pre-tensile deformation-contact heating-artificial aging process on the aluminum alloy structure, metallographic observations were performed on samples that underwent no pre-deformation as well as those that underwent 2%, 4%, 6%, 8%, and 10% pre-tensile deformation, followed by contact heating and artificial aging treatment at 120°C for 24 hours. As shown in Fig. 8, with the increase in deformation amount, the number of precipitated phases increases, and their size becomes finer, resulting in a dispersed distribution within the matrix. The pre-tensile deformation introduces strain into the aluminum alloy material, enhancing the strengthening effect of aging precipitation and improving the material's strength.

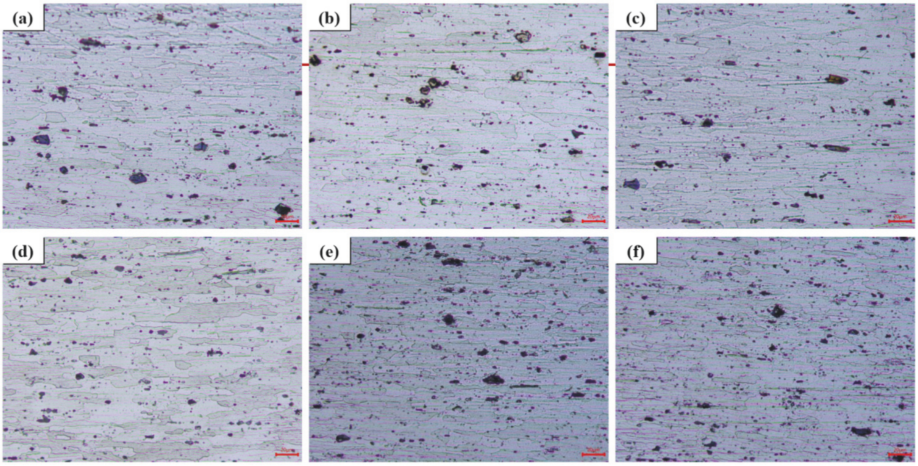

Fig.8. Microstructure Diagrams of Contact Heating Samples with Varying Deformation Amounts: (a) 0%; (b) 2%; (c) 4%; (d) 6%; (e) 8%; (f) 10%.

4. Conclusion

This paper takes the T6-state 7075 aluminum alloy as the research object and proposes a pre-stretching-contact heating-artificial aging process. By studying this process, the effects of contact heating and deformation on the structure and properties of aluminum alloy are investigated. The specific results and conclusions are as follows:

Compared with the conventional furnace solution treatment, the contact heating method can achieve the solution temperature within 30 seconds. After aging treatment, the tensile strength of the contact heating samples is significantly higher than that of the T6 state, outperforming the furnace solution treatment. Moreover, the peak aging time is advanced, with a peak tensile strength of 568.46 MPa, a yield strength of 507.81 MPa, and an elongation of 15.08%, showing a significant improvement in strength compared to the T6 state.

The pre-stretching method is applied to impart pre-deformation to the aluminum alloy material. As the deformation increases, the strength of the material continuously improves. After aging treatment with a 10% deformation, the maximum strength is achieved at 591.42 MPa, and the elongation remains at 14.4%, similar to that of the T6 state.

After contact heating, the aluminum alloy exhibits a high supersaturation of solid solution, which accelerates the precipitation process of the second phase. By imparting pre-deformation through pre-stretching, the number of precipitates increases as the deformation increases, leading to a uniform distribution in the matrix and enhancing the effect of precipitation strengthening.

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