Formability of 7000 aluminum alloys in warm and hot forming condition

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Formability of 7000 aluminum alloys in warm and hot forming condition

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Abstract. In recent years, the automobile industry has been calling for new lightweight solutions to fulfill increasing ecologically requirements. A weight reduction of automobile body constructions is necessary to reduce fuel consumption and CO_2 emissions. In order to reach this aim, new materials and novel forming processes are required. Also, the importance of aluminum alloys in the automobile industry is constantly increasing. Nowadays, mainly alloys of the 5000 and 6000 aluminum series are used for structure parts or shell parts, respectively. Another alloy series are the 7000 aluminum materials. These alloys offer a great lightweight potential due to their high specific strength combined with a moderate ultimate elongation. Nevertheless, these alloys are not yet widely used in the automobile industry. The reason is the limited formability of 7000 aluminum at room temperature in high-strength heat treatment condition. There are two approaches to increase the formability based on elevated temperatures, specifically the two processes of warm and hot forming at temperatures lower than the recrystallization temperature or above it, respectively. This paper deals with the investigation of the influence of forming conditions, especially the forming temperature. Trapezoidal parts were deep-drawn at different forming temperatures and subsequently investigated by determining the deformation with an optical measurement system as well as the springback of the material. In addition, the influence of the forming temperature on the flange feed was investigated as well as the influence of the paint bake process on the artificial aging step. Results show, that the formability increases with increasing forming temperature in the warm forming process route. Also, the artificial aging time can be decreased by a combined aging with paint bake heat treatment.

1. Introduction

Increasing requirements regarding exhaust emissions lead to several approaches to reduce the weight of automobiles. Especially the reduction of the car body weight is an expedient solution due to the high weight share of about 35 % of the body construction compared to the whole weight of the automobile [1]. Approaches to decrease the weight are for example lightweight processes to reduce the used sheet metal thickness like press hardening [2] or to use lightweight materials like magnesium [3] or fibre reinforced plastics [4]. Nowadays, the most common lightweight material in automobile industry is aluminum. In car body the alloy series 5000 and 6000 are used for structure or shell parts, respectively. However, highest strength aluminum alloys belong to the 7000 series. These materials have the same specific strength like press hardened steels in combination with an increased elongation at break [5]. Due to the limited formability at room temperature, these alloys have to be formed in special conditions [5]. Approaches to increase the formability are for example warm forming and hot forming. It is thus possible to decrease the weight of structure parts on the one hand and to reach equal or higher crash safety on the other hand. Therefore, using these alloys promote modern lightweight construction.

2. Process routes to form high strength 7000 aluminum alloys

The high strength of the 7000 aluminum alloys result in a limited formability in T6 condition at room temperature. Therefore, different approaches are examined to increase the formability like the W-temper process. Argandoña [6] investigated the formability of AA7075 at room temperature in the very ductile W condition. This temper condition is obtained by a solution heat treatment and subsequent quenching. Due to the natural aging of the material, this temper condition is unstable. An artificial aging process has to be carried out to reach the highest strength [7].

Another approach is the warm forming of high strength material in T6 condition shown on top in Figure 1. The dissolution of η' precipitations and dynamic recovery processes at elevated temperatures lead to an increased formability [8]. An improved formability was determined by Kumar et al. [9] and Sotirov et al. [5] for tubes consisting of EN AW7020 at 250 °C and EN AW7075-T6 as sheet material at temperatures above 170 °C, respectively. Due to the influence of the heating in the oven and the warm forming, an overaging of the material is possible [10]. Additionally, the mandatory paint bake process in automobile industry also affects the mechanical properties of the aluminum parts [11, 12].

In the hot forming process route shown in Figure 1 at the bottom, the aluminum is formed at temperatures above the recrystallisation temperature. In the first step the sheet material is heated up to solution annealing temperature. Subsequently the sheets are transferred into the tool and simultaneously formed and quenched [13]. Argandoña et al. [6] studied this process route and formed defect free b-pillars. After quenching, the parts are in W temper condition with low strength. To achieve proper mechanical properties an artificial aging step has to be carried out at 120 °C for 24 h. The increase in strength bases on the forming of finely dispersed metastable precipitations [13]. The precipitation sequence determined by Degischer [14] and Löffler [15] describes partially coherent η' precipitations as the main hardening phase for 7000 aluminum alloys. Behrens et al. also examined an influence of the quenching rate on the mechanical properties after artificial aging for EN AW7022 and EN AW7075 [11].

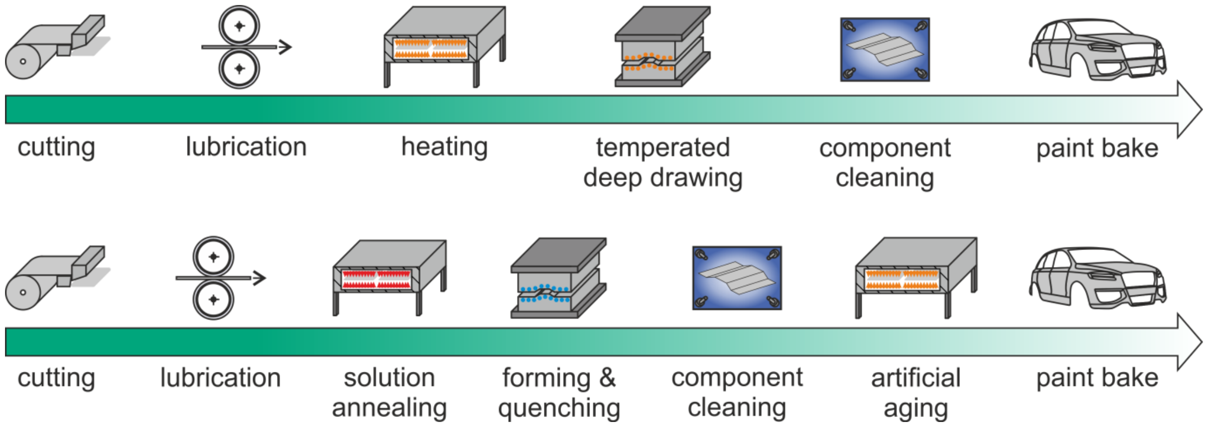

Figure 1. Process routes for warm forming (top) and hot forming (bottom) of 7000 aluminum alloys.

3. Experimental setup

For the experimental investigations two different aluminum alloys of the 7000 series were examined. Both alloys contain copper and are thus sensible for quench processes [7]. Due to its high formability, also a 5000 series alloy was used as reference material for the deep drawing test. The mechanical properties for both alloys are listed in Table 1. The stress and strain development for both 7000 aluminum alloys at different temperatures is described in [11].

Table 1. Investigated aluminum sheet metal materials.

	Sheet thickness (mm)	Ultimate tensile strength R_m (MPa)	Elongation at break A (%)	Copper content (wt%)
EN AW5182-O	2.0	~ 245 - 345	~ 11 - 16	0.15
EN AW7022-T6	2.0	496	12.7	0.5 – 1.0
EN AW7075-T6	2.0	569	14.1	1.2 – 2.0

For the investigation of the formability in warm forming a trapezoidal cup was deep drawn. The used drawring, blankholder and punch were heated up to forming temperature by heating cartridges. Both radii, of the punch and drawring, were 10 mm. The blank was heated separately in an oven and was held at forming temperature for 20 s before it was transferred to the tool. The temperature of the sheet was determined by a sheath thermocouple. The temperature drop after the transfer was compensated by the heated tool. A water suspension with solid lubricant (Bechem Beruforge 121 D) was used for the lubrication. The experimental setup is shown in Figure 2.

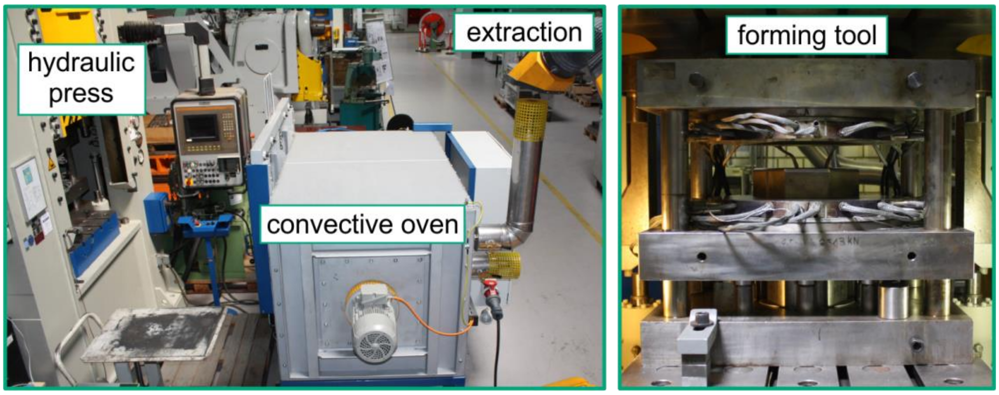

Figure 2. Experimental setup for warm forming.

To determine the influence of the forming temperature on the formability and the dimensional accuracy in the warm forming route, three different temperatures were selected for the investigations as listed in Table 2. The influence of the forming depth on the investigations was excluded by deep drawing all parts to 35 mm.

Table 2. Investigated forming temperatures for warm forming.

Material	Warm forming temperature (°C)
EN AW7022-T6 **EN AW7075-T6**	150, 200, 250

Following to the warm forming, the produced parts were investigated by two optical measurement systems. With a GOM Argus system the strain distribution on the surface of the parts was determined. Therefore, prior to the forming, a circular pattern was etched on the blank surface. The deformation of the pattern as a result of the warm forming relates to the major and minor strain at each point. Beside the strain distribution on the whole part, also two defined workpiece areas were examined; the punch radius and the middle of the part wall. Therefore, an intersection was made to investigate the strain distribution at these areas. For illustration purposes, coordinate x along the circumference of the component describes the strain distribution for the two respective areas. The starting-point of the coordinate is shown in Figure 3. A deep drawn part is shown in Figure 3 and the evaluated workpiece areas are shown on the right side. Additional, the dimensional accuracy and thus the springback were investigated by a GOM Atos system for each investigated alloy and warm forming temperature. A CAD-model was used as reference for the optical measured contour of the part. The flange outline is an indicator for the friction between the blank, blankholder and drawring. Therefore, the influence of the forming temperature on the outline was also investigated by the optical measurement.

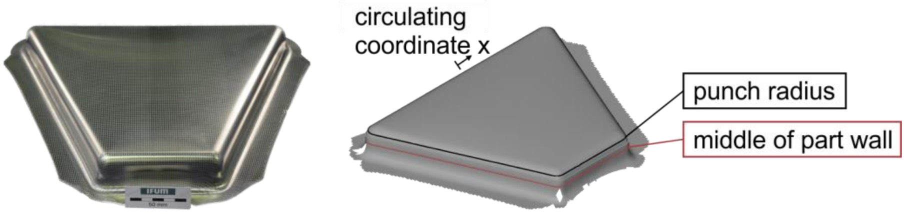

Figure 3. Deep drawn part (left) and investigated workpiece areas (right).

Another process route is the hot forming route with an additional artificial aging step after the deep-drawing. To ensure a high strength T6 condition, a typical artificial aging heat treatment takes 24 h at 120 °C. An artificial aging process in combination with the paint bake was investigated in order to reduce the time needed for aging. Therefore, a modified T6 heat treatment was conducted at various temperatures (120 °C, 150 °C and 180 °C) and different aging durations (6 h an 12 h). After this heat treatment the paint bake process was imitated in an oven at 180 °C for 20 minutes. The schematic time-temperature profile is shown in Figure 4. The blanks were solution heat treated for 5 min at 475 °C and quenched in a water cooled flat tool with a quenching rate of 200 K/s. The five days between the aging step and the paint bake process present a storage time in an industrial environment between the press shop and the paint shop. To determine the mechanical properties of the alloys after the heat treatment, tensile tests were conducted.

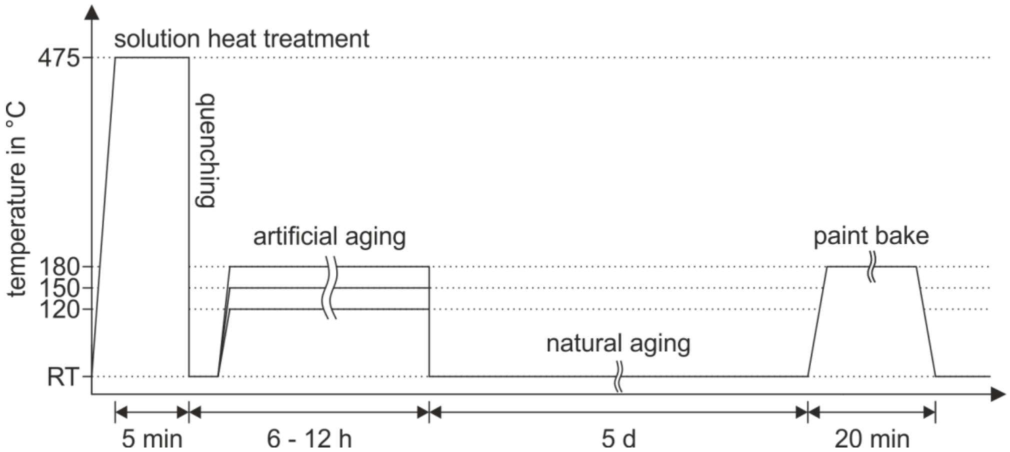

Figure 4. Schematic time-temperature profile for the investigation of the modified artificial heat treatment.

4. Results of the experimental investigations

Temperated deep drawing tests were carried out to investigate the influence of the forming temperature on the formability. Therefore, trapezoidal cups were deep drawn at 150 °C, 200 °C and 250 °C. A reference geometry was deep drawn with the aluminum alloy EN AW5182-O at room temperature. The achieved deep drawn height is shown in Table 3. With enhanced forming temperature it is possible to increase the deep drawing depth of the alloy EN AW7075-T6 from 35 mm to 45 mm. For EN AW7022-T6 a forming temperature of 150 °C is sufficient to reach the maximum depth of 45 mm.

Table 3: Determined deep drawing depth for the trapezoidal parts.

Material	Warm forming temperature (°C)	Deep drawing depth (mm)
EN AW5182-O	RT	40
EN AW7022-T6	150; 200; 250	45
EN AW7075-T6	150	35
	200	40
	250	45

Furthermore, the influence of the forming temperature on the strain distribution on the surface of the deep drawn parts was investigated. Therefore, a constant deep drawing depth of 35 mm was used. The results for EN AW7022-T6 are shown in Figure 5. The highest major strain was determined in the corner sections of the middle of the part wall with strains up to ε_1=0.6. An influence of the forming temperature for both investigated sections (punch radius and middle of part wall) cannot be determined.

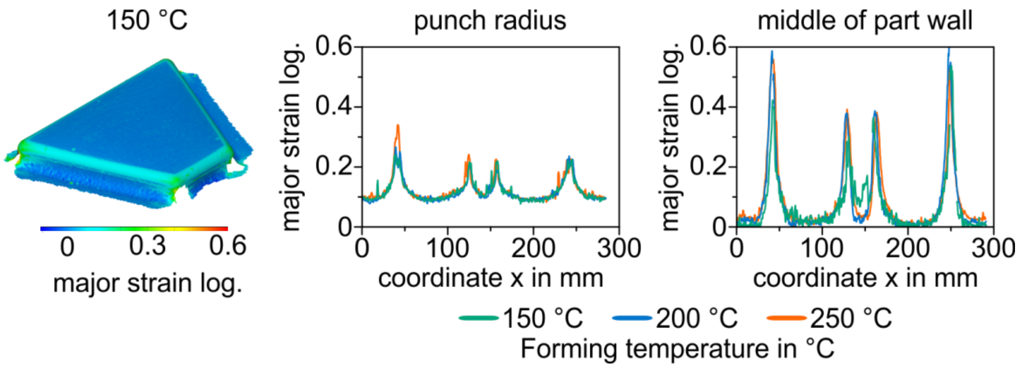

Figure 5. Distribution of the major strain at 150 °C forming temperature (left) and influence of the forming temperature on the major strain in the punch radius (middle) and at the middle of the part wall (right) for EN AW7022 T6.

A similar behaviour was also examined for EN AW7075-T6. The distribution of the major strain on the surface and the strain along the sections at the punch radius as well as the middle of the part wall is shown in Figure 6. Like EN AW7022-T6 the highest strain is determined in the corner section of the middle of the part wall with a value of ε_1=0.58. Also similar to EN AW7022-T6 the forming temperature has no significant influence on the strain.

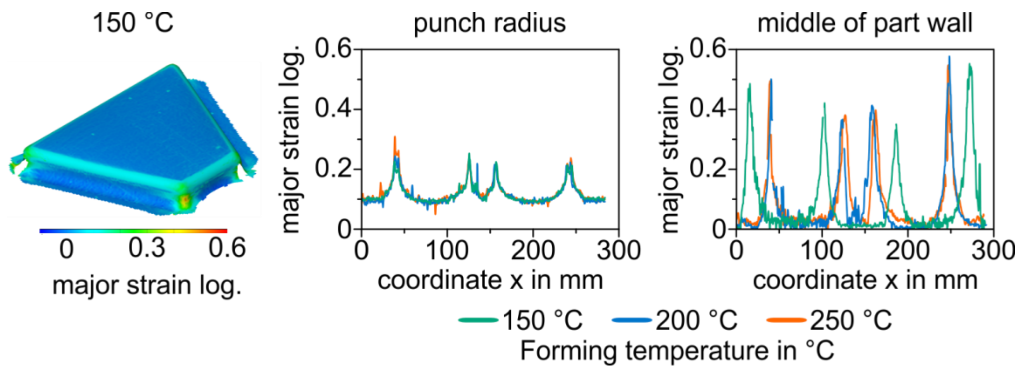

Figure 6. Distribution of the major strain at 150 °C forming temperature (left) and influence of the forming temperature on the major strain in the punch radius (middle) and at the middle of the part wall (right) for EN AW7075 T6.

In Figure 7 is the deviation between the deep drawn parts and the CAD reference model shown. The highest deviation between the formed parts and the reference is determined in the bottom section of the parts. Due to thermal expansion of the material and the use of a drawring instead of a die, the accuracy in this section is minimal. In contrast, the dimensional accuracy in the flange area is accurate. This also reflects in the springback investigation. The angle between the flange of the formed part and the CAD-model is between 0.72 ° and 2.38 ° for both materials and every forming temperature.

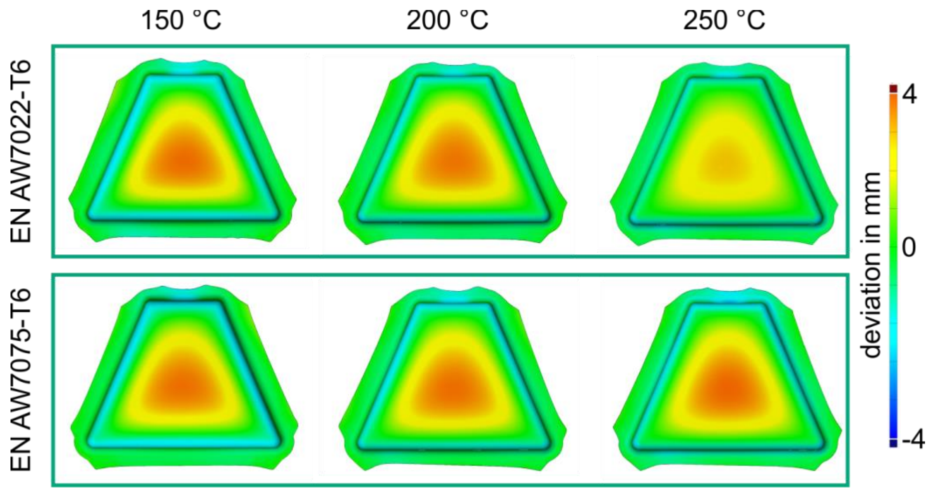

Figure 7. Influence of the forming temperature on the dimensional accuracy

The influence of the forming temperature on the flange outline is shown Figure 8. For both materials no influence of the forming temperature on the flange outline was determined. The captured outlines have almost the same contour. Therefore, the forming temperature has no significant effect on the used tribological system between blank, lubricant and forming tool.

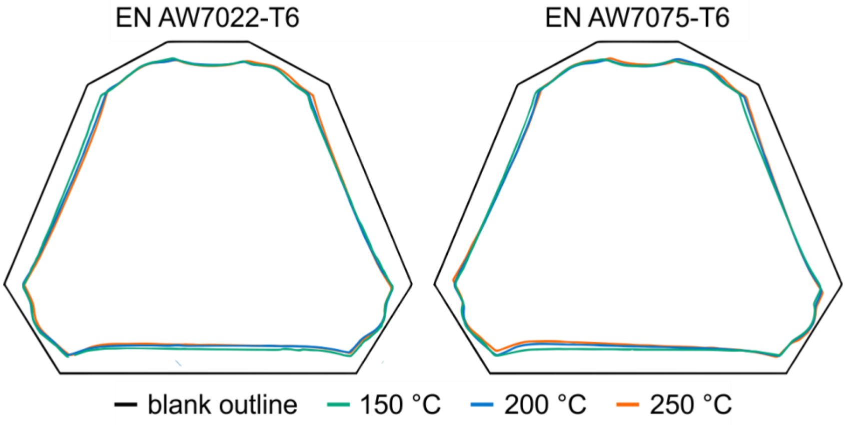

Figure 8. Influence of the forming temperature on the flange outline after forming

Moreover, by combining the heat treatment with the paint bake process, the reduction of the artificial aging time after hot forming was determined by tensile tests. The results for EN AW7022 and EN AW7075 are shown in Figure 9 and Figure 10. The typical T6 heat treatment is shown on the left side of the diagram as reference. With an artificial aging time of 6 h and 12 h at 120 °C and combined paint bake it is possible to obtain the same strength level as with a T6 heat treatment for EN AW7022. For EN AW7075 a slight decrease in strength from 569 MPa to 542 MPa for 6 h and 12 h aging time at 120 °C is determined. With increasing aging temperature the strength decreases for both materials. An increase in elongation at break was studied for EN AW7022 with an aging time of 6 h and 150 °C.

Afterwards, the elongation decreases with increasing aging temperature. For EN AW7075 an aging temperature of already 150 °C together with an aging time of 12 h leads to a decrease of the elongation at break.

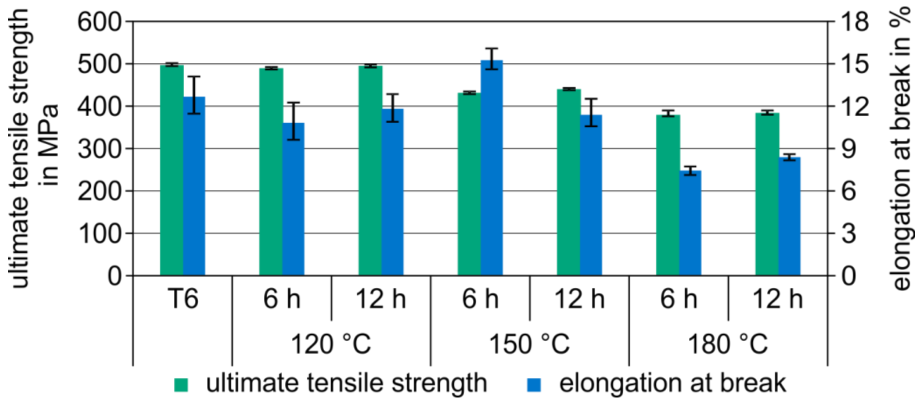

Figure 9. Mechanical properties of EN AW7022 after artificial heat treatment and combined paint bake.

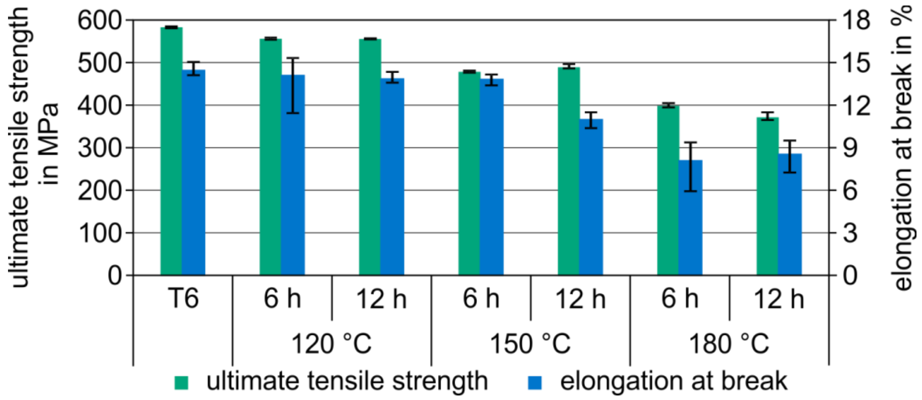

Figure 10. Mechanical properties of EN AW7075 after artificial heat treatment and combined paint bake.

5. Summary and Outlook

In this paper, influences on the formability in warm forming and mechanical properties in hot forming of the aluminum alloys EN AW7022 and EN AW7075 were investigated. It was shown that the temperature has an influence on the deep draw-ability for EN AW7075. With both alloys it is possible to obtain an increased draw depth compared to the reference material EN AW5182-O. In further investigations, the influence of the forming temperature on the strain distribution was discussed. Thereby, no significant influence was investigated for the workpiece sections in the punch radius and the middle of the part wall. Also no influence of the forming temperature in warm forming was determined on the dimensional accuracy and the flange outline. Hence, increased forming temperatures above 150 °C have no positive effect on the formability of the alloy EN AW7022. In contrast, the alloy EN AW7075 requires greater forming temperatures for the same formability. This can be attributed to the increased tensile strength of EN AW7075 compared to EN AW7022. Moreover, the reduction of the artificial aging time in the hot forming route by combining the heat treatment with the paint bake process was investigated. A reduction of the artificial aging time by 75 % compared to a typical T6 heat treatment was achieved for both alloys. This leads to a significant reduction in process time for the hot forming route. In further investigations, the influence of the heat treatment on the stress corrosion and the influence of the forming temperature on the friction will be investigated.

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