Material properties of ultra-high strength aluminium alloys: a comparative study of various material suppliers

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In the present work the influence of industry-standard heat treatment on ultra-high strength aluminium alloys has been investigated under terms of various forming processes. For this purpose, a scaled side impact beam was formed out of AA7075 via Hotforming and W-Temper techniques and subjected to a heat treatment process. The test material was taken from several material suppliers in order to identify any variation of the mechanical properties. Based on uniaxial tensile tests the final material properties were evaluated and compared. Using the W-Temper and Hotforming process, the parts produced without a subsequent heat treatment show no influence concerning the suppliers. A significant difference of the material behaviour can be seen if single-step paint bake cycle is applied. Here, the ultimate tensile strength (UTS) values and those for yield strength vary up to 9% and 16% respectively.

1. Introduction

One possibility to pursue lightweight strategies is to substitute materials with one indicating higher specific strength values. Aluminium and its alloys offer a high and cost-effective lightweight potential. Previous investigations have shown that weight savings of more than 40% can be achieved if aluminium alloys are used instead of steel; even if crash-relevant components such as side impact beams are considered [1]. Amongst other things, the high strength to density ratio of aluminium positively influences fuel consumption as well as emissions and therefore plays a major role in automotive or aircraft engineering. A study published by Ducker Worldwide [2] shows that the average aluminium consumption per car produced in Europe almost tripled between 1990 and 2012.

By 2020 the amount of aluminium used in cars is expected to rise to an average of 180 kg if small and medium-sized cars follow the trend recorded in high end models [2]. Compared to steel, which currently dominates the market due to its good price-performance ratio, the forming behaviour of high and ultra-high strength aluminium alloys is still restricted at room temperature [3]. With the aim of improving their formability several forming methods have been developed in order to substitute the conventional cold forming process. Currently, complex-shaped components made out of high and ultra-high strength aluminium alloys, such as from the 7000 group, can be produced reasonably economically using the Hotforming [4, 5], the Warmforming [6] or the W-Temper [7] process.

However, the influence of forming processes combined with industry-standard heat treatment on AA7075 material obtained from various suppliers has not been investigated sufficiently. For this purpose, a scaled side impact beam (see Table 2) is manufactured using different thermal assisted processes and then exposed to a subsequent heat treatment (single-step paint bake cycle). Afterwards characteristic material properties such as strength and elongation values are determined as a function of both the supplier and the manufacturing process.

Table 1: Comparison of the mechanical properties of EN AW 7075 provided by various suppliers

EN AW-7075 T6 temper	Nominal thickness [mm]	Hardness [HBW]	Min. proof stress [MPa]	Min. tensile strength [MPa]	Min. elongation at break [%]
Supplier A	2	150	455	530	7
Supplier B	2	-	500	565	12
Supplier C	2	150	500	560	7
Supplier D	2	-	480	540	10

2. Experimental

The mechanical properties from formed side impact beams out of EN AW 7075 are compared to each other.

Table 1 shows the characteristic material parameters for EN AW 7075 in T6 condition based on the manufacturer's specifications, which are referred to as Supplier A-D in the following.

The initial blanks are cut from the AA7075 materials and formed into a demonstrator side impact beam using the Hotforming and W-Temper process. These two forming techniques were selected since there is no influence of possible delivery variations due to the accompanied solution heat treatment prior forming. In the Hotforming process the blank is heated up in a furnace to its solution heat treatment temperature (465 °C < T_{SHT} < 494 °C). The temperature is maintained for a period of time in order to dissolve the coarse

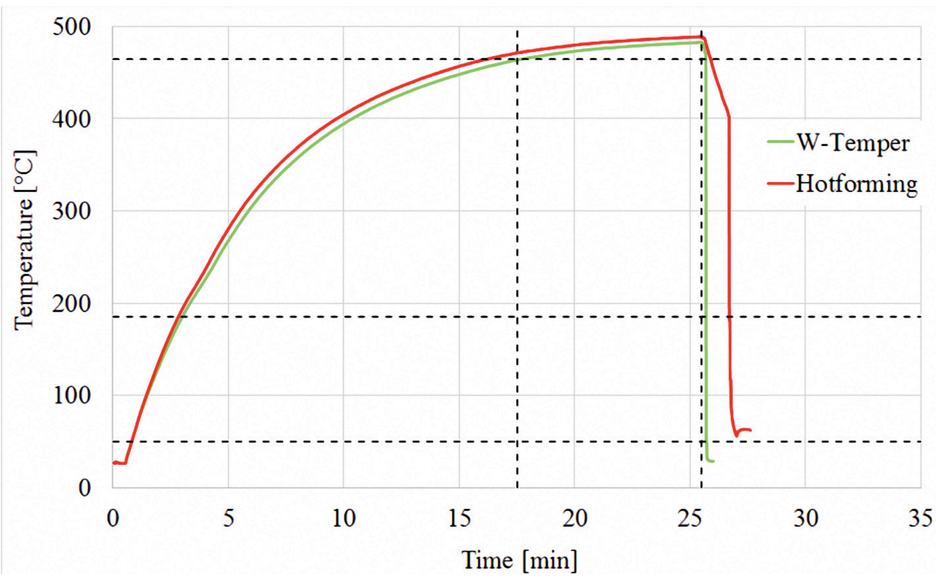

Fig. 1: Temperature curves of the Hotforming and W-Temper process

Table 2: Procedure of the test series

Process	Heating Temp. [°C]	Holding time [min]	Quenching and forming	Ageing	Specimen area (same for both processes)
Hotforming	465 - 490	8	Forming tool at RT	One week natural ageing, then with/ without heat treatment	
W-Temper	465 - 490	8	Water bath then forming tool at RT	One week natural ageing, then with/ without heat treatment	

precipitates and soluble inclusions. Afterwards, the blank is quickly transferred into the forming unit where it is formed and held between the cold dies to quench the material to lower temperatures. The critical cooling rate for AA7075 is approx. 100 K/s and should be maintained below 200 °C in order to avoid quench induced precipitations or a loss of its hardening potential [8].

The W-Temper process is, in contrast to the Hotforming process, a thermally decoupled forming technique. The blank is first heated in the furnace, kept at solution heat treatment temperature and then quenched. Depending on the desired cooling rate the blank can be quenched using a water bath, flat plates, spray cooling or compressed air. Afterwards, the cold blank is formed at ambient temperature and cut by laser or directly in the tool before the natural ageing of the material takes place. The temperature curves of the described processes are shown in Fig. 1.

In order to achieve a stable T4 condition between forming and further heat treatment the material was naturally aged for one week. Afterwards, tensile specimens according to DIN EN ISO 6892 were taken directly from half of the components produced. The other half was subjected to heat treatment and tensile specimens were subsequently taken from the flank area (see Table 2). The heat treatment is carried out at 180 °C for 20 min and thus corresponds to the industry standard of single-step paint bake cycle (1 PB) for AA 6xxx car body materials.

3. Supplier comparison

The following results are based on the mean value of 3 components and show the variation of the material parameters: ultimate tensile strength (UTS), yield strength σ_y and fracture elongation ε_f which were determined in the tensile tests.

3.1. Hotforming process

Using the Hotforming process the parts produced without subsequent heat treatment show no supplier influence, since the strength and elongation values vary only within a small range of 15 MPa and 1.8%. Supplier C shows the highest UTS value of 515 MPa. A significant difference of the material behaviour can be seen if single-step paint bake cycle is applied. Here, the UTS and yield strength values vary up to 73 MPa (≈ 14%) and 120 MPa (≈ 25%) respectively. The material from Supplier A shows an average UTS value of 533 MPa. In relation to the specified minimum ultimate tensile strength of 530 MPa, the material regains 100% of the strength in T6 condition after forming and applied heat treatment.

Further it can be seen that with a subsequent heat treatment step the yield strength increases and the elongation at break decreases for each material. The greatest increase in yield strength is seen from the material of Supplier A, indicating an increase of 140 MPa. At the same time, the elongation at break decreases significantly by 10%. Except for the material of Supplier A, the ultimate tensile strength values decrease for all suppliers if a single paint bake step is applied.

3.2. W-Temper process

Using the W-Temper process the parts produced without subsequent heat treatment show no supplier influence as the values recorded remain almost constant. The strength and elongation values vary only by 27 MPa and 1.7%. The material from Supplier B shows the highest tensile strength value with an average of 523 MPa. In relation to the minimum tensile strength specified by the manufacturer, a decrease in strength to 96% of the initial strength level at T6 condition is achieved. If a single-step paint bake cycle is applied, the same trends can be detected as in the Hotforming process. The UTS and yield strength values vary within a range of 46 MPa (≈ 9%) and 74 MPa (≈ 15%) respectively.

In addition, it can be seen in Fig. 3 that after the heat treatment step the yield strength increases while the elongation at break decreases. The greatest increase in yield strength (189 MPa) and decrease in elongation at break (9.3%) can be observed for the material from Supplier A. Compared to the Hotforming process the strength values are higher while the variation of values is lower. This is caused by the cooling rate which is higher and more constant due to the water bath. In the Hotforming process the transfer of the blank from furnace to press was performed manually.

The increase in yield strength can be ex-

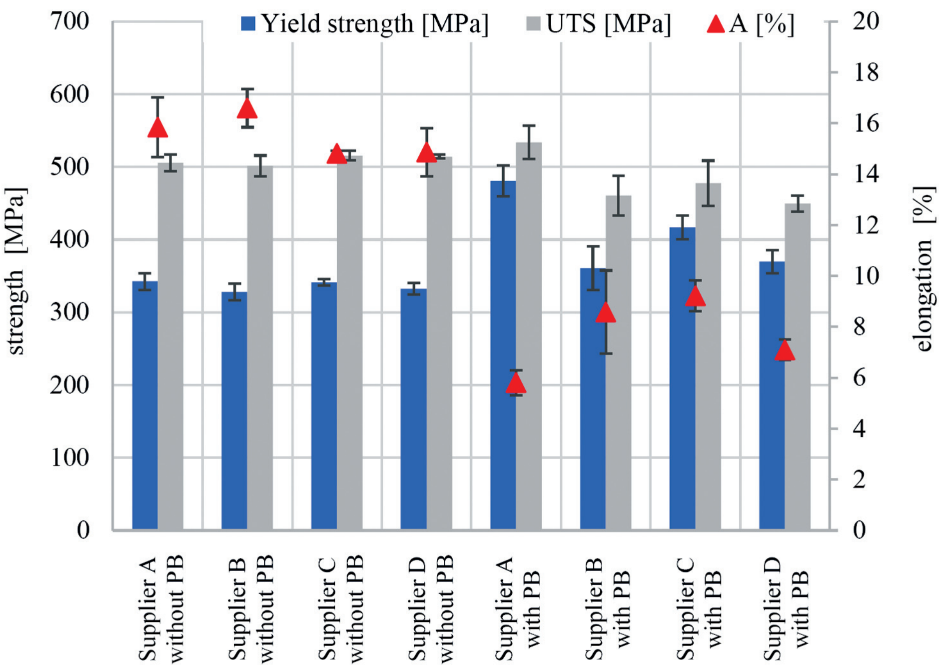

Fig. 2: Test results of the supplier influence based on the Hotforming process

plained by precipitation hardening during artificial ageing since the precipitates and the corresponding lattice strains act as obstacles to dislocation motion. With regard to the results obtained it becomes clear that the quenching rate has a high influence on the achievable strength in the Hotforming and W-Temper process. During heat treatment, this is characterised by the same tendencies but differing absolute values and higher standard deviation.

The experimental results obtained in this paper are consistent with the investigations of Oberhauser et. al [9], where AA7075 material was investigated using the W-Temper process with a subsequent heat treatment (5 cycles of PB). Here, the results also showed an increase in the yield strength from approx. 400 to 460 MPa while the tensile strength values remained almost constant at 540 MPa.

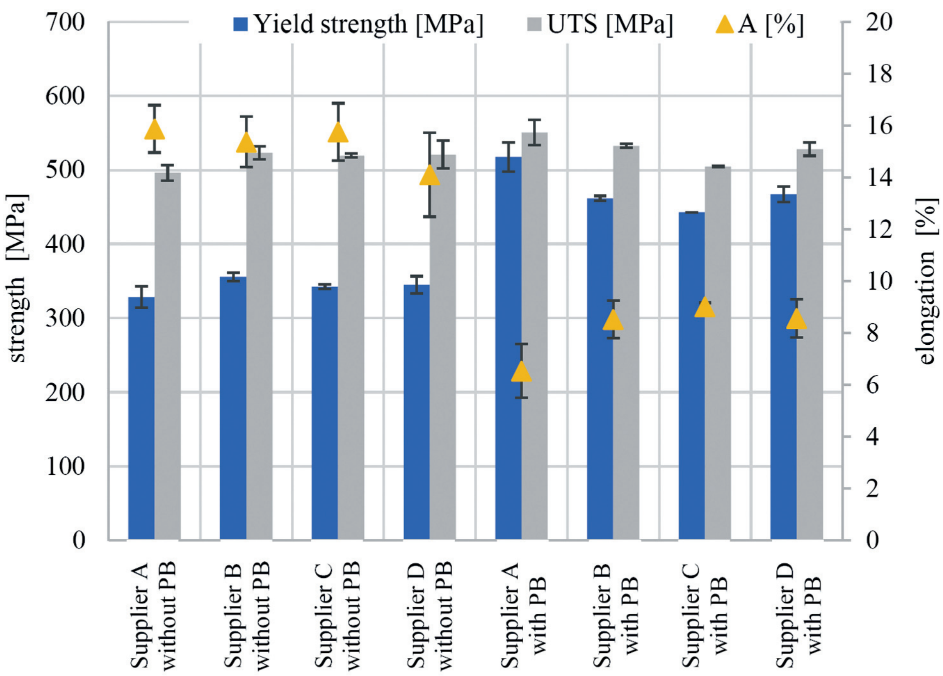

Fig. 3: Test results of the supplier influence based on the W-Temper process

4. Conclusion

Using the Hotforming and W-Temper process, the parts produced without subsequent heat treatment show no influence concerning the suppliers since the strength and elongation values vary only within a small range of 15 MPa and 1.8%. A significant difference of the material behaviour can be seen if single-step paint bake cycle is applied. Using the Hotforming process the UTS and yield strength values vary up to 73 MPa (≈ 14%) and 120 MPa (≈ 25%) respectively. The same trends can be detected for the W-Temper forming process. The UTS values and those for yield strength vary within a range of 46 MPa (≈ 9%) and 74 MPa (≈ 15%). For both processes the highest strength values could be achieved using material from Supplier A where a heat treatment step seems to have no negative on the mechanical properties.

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