Hot stamping of AA7075 aluminum sheets

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Abstract. In this work the formability of a high strength aluminium alloy (AA7075-T6) for the stamping of an automotive component has been studied. Due to the low formability of the selected alloy, two different heat assisted forming strategies have been analysed. On the one hand, the W-temper process, where the thermal process is carried out prior to the forming operation. On the other hand, the hot stamping process, where the thermal process is carried out at the same time as the forming. The results showed that both technologies were able to form the component avoiding any failure of the material. On the contrary, both processes reduced the final mechanical properties of the material compared to the as received material condition. However, the obtained mechanical properties doubled the strength of commonly used 5xxx and 6xxx aluminium alloys.

1. Introduction
In the last years, the automotive industry is facing an enormous challenge to lightweight the current cars mass and for complying with the new environmental and safety regulations. The weight of the car has to be reduced in order to reduce the fuel consumption and the CO₂ emissions while the car body has to be improved to overtake the new safety standards.

These objectives have been achieved by the introduction of new materials in the car body. New cold formable high strength steels are being developed with strength levels of around 1200 MPa. In the same context, carbon fiber is being used in high-class cars such as BMW 7 Series. Other OEMs, such as Audi and Jaguar Land Rover, have decided to push the use of aluminium alloys in order to make use of the good strength to weight ratio they present.

Medium strength 5xxx and 6xxx aluminium families are being already used in the body in white and skin parts of several commercial cars. However, the strength to weight ratio of these families is not yet the optimum one for security crash components and to get the desired accepted cost per kg saved. In this regard, the 7xxx family is the next potential aluminium series to be introduced on the market. The main disadvantage of this family is its reduced formability at room temperature.

One of the alternatives to increase the formability of the material is to increase the forming temperature. However, being an age-hardenable family, the increase of temperature during forming degrades the final mechanical properties of the material. Regarding the forming process, Lee et al. [1] studied the warm hydroformability of 7075 tubes between room temperature to 300°C. The results showed that sufficient formability of high strength aluminium alloys could be achieved by the selection of the pertinent pre-treatment conditions and deformation temperatures. Wang et al. [2] presented a paper where material characterization and LDR tests were performed using the 7075-T6 material. They found that total elongation at fracture increased between 140 °C and 220 °C due to the increase in strain rate sensitivity, which controls diffuse necking and prevents plastic strain from concentrating in a localized neck.

Regarding the possible technologies to stamp the high strength aluminium alloys, three different technologies can be found: the warm forming, the hot stamping and the W-temper forming. On the warm forming, both blank and dies are heated during the process [2-3]. However, the heating of the dies critically increases the forming costs and set-up and maintenance aspects. The hot stamping process is being widely used on boron steels for safety components [4]. In this process the blank is heated in a furnace and then transferred to the press where the forming is performed with dies at room temperature, significantly reducing the cost of the process [5-6]. When using boron steels, the dies are kept closed after the forming for direct quenching of the material.
The W-temper process, on the other hand, is an uncoupled thermal-forming process [7]. First the blank is heated in the furnace and subsequently quenched for solution heat treating of the alloy reducing its strength and increasing the formability of the material. Before the natural ageing and strengthening of the material and taking advantage of that time window, the forming is performed to make use of the formability improvement.

2. Selected automotive component and aluminium alloy

In this work, a high strength aluminium automotive component has been formed with both hot stamping and W-temper methods. The selected component has been a structural component, namely the front side member of the Volkswagen Touran passenger car (see circle in red in ‘figure 1’). In ‘figure 2’ the catastrophic result of the room temperature forming of the component using the 7075 aluminium alloy at T6 condition is shown.

![Figure 1. Front side member of VW Touran.](image1)

![Figure 2. RT forming of 7075-T6 alloy.](image2)

For the study the aluminium alloy AA7075-T6 of 1.5 mm thickness has been used. In table 1 the as-received mechanical properties obtained by ASTM E8-04 standard tensile tests are summarized.

| Material     | Thickness | Rp02  | Rm   | A%  |
|--------------|-----------|-------|------|-----|
| AA7075-T6    | 1.5 mm    | 540 MPa | 590 MPa | 10% |

3. Temperature assisted forming

As mentioned before, two different manufacturing processes have been studied: a) the hot stamping process and b) the W-temper process. In the hot stamping process, the blank has been first heated up to 500 °C and maintained for 300s in a resistance furnace. Secondly, the blank has been transferred to the dies using a robot arm in approximately 7s. While the blank is still at high temperature, the forming process has been carried out and the dies have been kept closed during 10s to force the fast cooling of the material. ORAFOR WD from CONDAT Lubrifians company, water diluted at 10% lubricant, was sprayed on the dies in order to avoid galling issues.

The second variant, the W-temper, is an indirect process where the microstructure of the material is modified prior to forming. Similarly to the hot stamping process, first the blank has been heated up to 480 °C and maintained for 300s in a resistance furnace. Then the blank has been transferred to a water bath using a robot arm and quenched for its solution heat treatment, modifying its initial microstructure. Finally, the forming has been conducted at room temperature without having to maintain the dies closed. In table 2 the advantages and disadvantages of each technology (compared to each other) are shown.
Table 2. Advantages and disadvantages of each technology.

| Technology  | Advantages                                      | Disadvantages                                                   |
|-------------|------------------------------------------------|----------------------------------------------------------------|
| Hot stamping| No critical time managing                       | Bigger process time (dies have to be closed after forming)      |
| W-temper    | Forming is performed at room temperature (less galling, tool maintenance, tool cost) | Critical time managing (forming before aging) Tool costs and maintenance are higher |

A summary of the testing conditions used in this work are presented in table 3.

Table 3. Hot stamping and W temper manufacturing processes.

| Manufac. Method | Heating time | Heating temperature | Pre-Forming | Press closing time |
|-----------------|--------------|---------------------|-------------|-------------------|
| Hot stamping    | 300 s        | 500 ºC              | No          | 10 s              |
| W-temper        | 300 s        | 480 ºC              | Yes         | -                 |

After forming, geometrical measurement of the components has been performed and the final mechanical properties have been evaluated from tensile samples cut from two different zones of the component.

4. Dimensional accuracy of components

A metrology inspection of the hot stamped and W-Temper formed components has been conducted using the GOM ATOS® system. ‘Figure 4’ shows the geometrical deviations of both components in comparison to the theoretical tool geometry definition.

Higher geometrical accuracy is observed for the hot stamping technology.

Figure 3. Metrology inspection report: A) and B) the hot stamped component from different side views and C) and D) the W-temper component.
5. Final material properties
As previously mentioned by Lee et al. [1], the thermal history of the blank during the process could degrade the final mechanical properties of the material. In order to analyse the mechanical properties of the final component, standard tensile samples after the ASTM E8-04 standard have been cut off using wire EDM technology from the component as shown in ‘figure 5’ for both process variants.

![Figure 4](image.png)

**Figure 4.** Tensile test samples location on the final component.

The ‘figure 5’ presents the comparative between the final mechanical properties and the as-received material for the both studied forming strategies. It can be shown that both technologies reduce the mechanical properties from a Yield Strength of about 540 MPa to a new one of around 280 MPa.

![Figure 5](image.png)

**Figure 5.** Comparison of tensile test results.

Square and triangle data markers represent the reference AA5754-H111 and the AA6111-T4 automotive aluminium materials’ tensile properties. As it is clearly observed, the modified AA7075 aluminium components formed by hot forming and using the W-Temper process, even after losing mechanical properties from the as-received condition, still have approximately double strength compared to the well-known reference alloys. Comparison of changed strength levels due to bake hardening effects after a typical e-coating process cycles are not available.

6. Discussion and conclusions
In this work, two different technologies have been analysed in order to overtake the low ductility problem when forming the AA7075-T6 high strength aluminium alloy. The hot stamping and the W-temper technologies have been found to be valid to form the desired components without cracks.
Regarding the geometrical accuracy, the metrology inspections have shown that the hot stamping process gives higher accuracy compared to the W-temper process. The main disadvantage of both processes is the degradation of the material mechanical properties during the forming process. However, the final properties obtained almost double the ones presented by 5xxx and 6xxx reference alloys used in the automotive industry. The post heat treating of formed components using the e-coat process used in serial production is still under study.

Acknowledgments
The authors would like to acknowledge the support of the industrial partner and automotive tool maker BATZ S. Coop. company.

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