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W-TEMPER FORMING OF AA7075 ALUMINUM ALLOYS AS AN ALTERNATIVE TO THE WARM AND HOT STAMPING

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Abstract

As important light-weight structure material, aluminum alloys have been widely used in automotive and aerospace industries. In the last years, the manufacturing of parts with high strength and good dimensional accuracy has become the main objective in industrial applications. Within the available aluminum alloys, the 7xxx series has attract the interest of the industrial designers due to the high yield strength and ultimate tensile strength they present. However, the formability of these alloys in as-received industrial condition is very poor at room temperature and various studies are being carried out to develop efficient warm and hot forming processes to form them industrially using heated tools. In the present paper, the W-temper forming is studied as an alternative to the warm and hot forming processes. Heat treatment temperatures and critical times are presented and an industrial B-Pillar is formed to validate the new process. In the last chapter, the final mechanical properties of the part are reported, before and after a virtual e-coat process where the W-temper forming is compared with a hot stamping process.

Key words: AA7075, W-temper forming

1. INTRODUCTION AND MOTIVATION

Several examples exist where the principal OEMs have replaced medium strength alloys by ultra-high strength alloys to produce ultra-light body-in-white concepts. A very good example is the early ULSAB project started in 1995 and leaded by the principal steel makers to develop new advanced steels where a 25% of weight reduction was possible keeping the structural behavior. Several successful research projects have been realized since then to introduce new steels in the automotive industry. Components using very high strength Dual Phase, Complex Phase, TRIP and Martensitic steels are a reality and Press Hardened parts are already present in our cars which helps reducing the CO_2 emissions and fuel consumption. If we focus in a future horizon, the high bend stiffness and strength to weight ratio of aluminum alloys combined with their significant corrosion resistance and recyclability mark them as ideal candidates to replace the heavier steel components in the automotive industry.

Despite all these advantages, aluminum alloys still lag behind in their application due to their poor formability as compared to steels and their higher cost. Few OEMs consider the aluminum alloys as a candidate for the production of their body-in-white and full aluminum ones are limited to medium to high class vehicles. However, the multi material body-in-white concepts and the emerging new joining technologies could enable the use of ultra-high aluminum alloys if the lightweighting cost is low. Medium strength 5xxx and 6xxx series aluminum alloys are common and proven alloys for the auto-

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motive structural parts and body-in-white in European cars. Good reviews have been realized by Kleiner et al. (2003) and Wang et al. (2012) where warm forming of these alloys is also included to increase their formability and form more complex parts. However, for some high security crash parts like the B-pillar, a higher level of strength to weight ratio is required to satisfy the roof crush and side impact standards and the 7xxx aluminum alloys are the next family to be studied to fulfill with the OEMs requirements. Other authors investigated 7xxx alloys related to forming and crash performance, respectively. They concluded that 7xxx-series alloys have potential to replace steel for structural components like A-pillar, B-pillar and side impact beams. The 7xxx-series alloys are age-hardenable alloys in which strengthening arises due to the formation of fine dispersed meta-stable precipitates during specific heat treatments such as T6, which is the most common industrial available condition.

The formability at room temperature is poor and new forming methods like the warm forming and hot stamping are under research and very few studies using these technologies have been published for the 7xxx alloys. One of the major problems associated with forming at elevated temperatures is degradation of high strength temper of the age-hardenable aluminum alloys, as reported by Lee et al. (2004) for AW-7075-T6. Regarding the forming process, Lee et al. (2004) studied the warm hydroformability of 7075 tubes between room temperature to 300ºC. The results showed that sufficient elongation properties of high strength aluminum alloys could be achieved by the selection of pertinent pre-treatment conditions and deformation temperatures. Wang et al. (2012) 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 140ºC and 220ºC due to the increase in strain rate sensitivity which controls diffuse necking and prevents plastic strain from concentrating in a localized neck.

They further reported that the best drawing and stretching formability can be realized at temperatures between 180ºC and 220◦C, respectively. No scientific publication has been found where the hot stamping of the 7075 aluminum alloy has been studied. Fan et al. (2013) studied the hot forming of the 6A02 alloy using warm forming dies. The optimal temperature for the forming dies was reported to be near 250ºC. On the other hand, Bariani et al. (2013) presented a paper where the hot stamping of the 5083 aluminum alloy was analyzed as an alternative to the super plastic forming process. Cool dies were used in the study and the formability of the material was analyzed at temperatures up to 500ºC. The results of industrial trials carried out on an automotive component with a complex geometry confirmed that the forming temperature of 450ºC can assure a geometrically sound component, with microstructural and mechanical characteristics comparable of those of the as-delivered blanks.

2. MOTIVATION AND RESEARCH APPROACH

Warm and hot forming often present advantages from the point of view of formability. However, industrial companies frequently avoid the use of these technologies due to its higher cost which is directly linked to the high cycle times, extra investment in heating ovens and fast lank positioning robots and bigger wear and galling problems of the tools as well as the complexity of the temperature control in the tooling. Due to the previous facts, in the present paper the W-temper process is put face to face with the hot forming process and the final properties of the stamped parts are compared. In the W-temper process, the aluminum AW-7075-T6 sheets are first solution heat treated and water quenched and subsequently formed at room temperature.

In order to draw the guidelines for the W-temper process design, tensile tests ranging from room temperature to 400ºC are presented to identify the potential application field of the warm and hot forming. Formability is compared to the ones obtained using the W-temper approach which has been optimized using laboratory specimens. Using these results, the final industrial validation case study and the process variables are defined. A B-Pillar is formed using the Hot Stamping and the W-temper process variants and the final mechanical properties are compared after a simulated e-coat process.

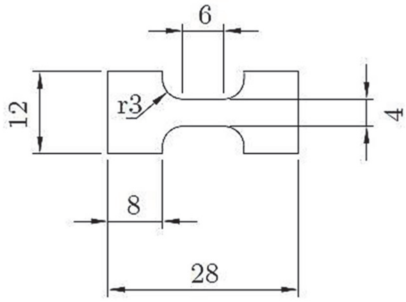
3. EXPERIMENTAL TESTS AT LABORATORY LEVEL

3.1. Uniaxial testing at various temperatures

AW-7075-T6 sheets with a thickness of 1.6 mm and chemical composition (in wt.%) of 0.08 Si, 0.28 Fe, 1.57 Cu, 0.022 Mn, 2.35 Mg, 5.64 Zn, 0.19 Cr, 0.027 Ti, have been used in the current work. Tensile samples with a gauge length of 6 mm (see figure

1a) were machined from the as-received sheet in the rolling direction. Tension tests were performed using a MTS 810 servo-hydraulic testing machine equipped with an electrical oven of the same brand. Each tensile sample was heated to the test temperature in 5 minutes before each tensile test. The elongation of the specimen was directly measured form the machine grips movement as very small differences were measured when using an extensometer for the needed forces. A detailed view of the experimental set-up is shown in figure 1b. Tension tests were performed at temperatures between room temperature and 400ºC and at strain rates between 0.01 and 0.1 s^{-1}. The tests were repeated at least three times to ensure reproducibility.

a)



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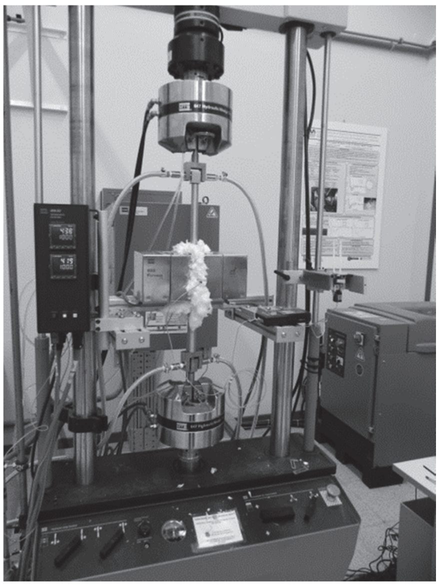
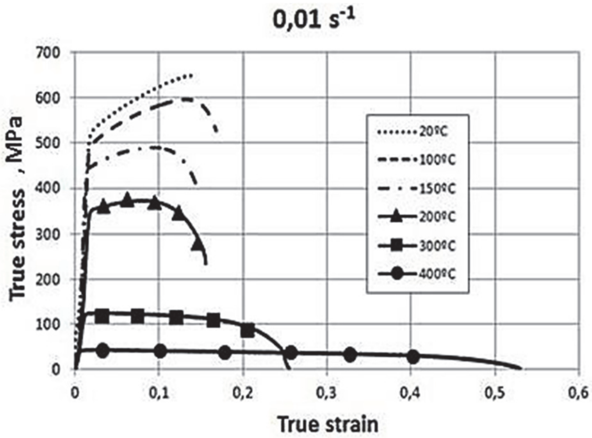


Fig. 1. Tension test sub-size specimen (a), testing machine and heating electrical oven (b).

Flow curves from the tensile tests of the as-received sheets are shown in figure 2.

a)



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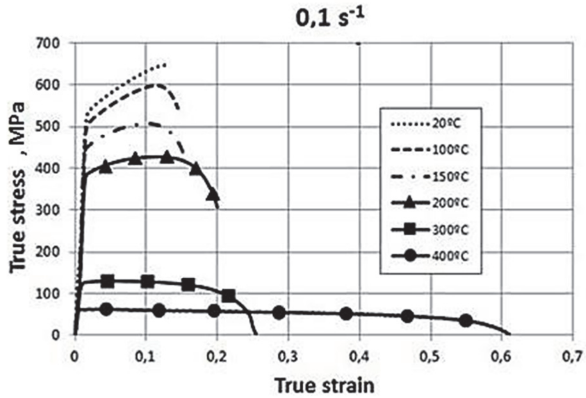

Fig. 2. Flow curves at different temperatures: strain rate of 0.01 s^{-1} (a) and strain rate of 0.1 s^{-1} (b).

The room temperature flow curves at different strain rates are almost identical, so it is observed the strain rate has a negligible influence on the strain hardening rate at this temperature. The flow curves at temperatures between 150 ºC and 400ºC are found to be sensitive to strain rate. True uniform strain decreases with increasing the temperature and the true fracture strain increases with increasing temperature only above 150ºC. The strain hardening decreases a lot above 200ºC being a very important parameter to obtain very deep drawn parts. It is known that the formability of the as received AW-7075-T6 alloy is very poor to produce drawn parts.

These tensile test results show the warm drawing temperatures are in the range of 150ºC - 300ºC since the process designer still can use the strain hardening of the material to pull the material from the blank holder areas to the drawing zones. At higher temperatures, the formability increases but there is a negligible strain hardening. Thus, these temperatures ranging from 300 to 500ºC are the most promising ones to use the hot stamping process to produce semi-opened and small depth parts such as reinforment profiles, pillars and roof members.

3.2. Characterization of the solution heat treatment

Aiming to optimize the future industrial process of the W-temper forming strategy, as received material was longitudinally cut in small pieces of 100x20 mm and solution heat treated using different oven temperatures and times. 470ºC was proven to be a good compromise for the reduction of the hardness in a small time. In order to identify the minimum oven time to be used using this oven temperature different solution heat treatment tests were performed varying the oven time followed by a water quenching and direct trough thickness hardness measurement from a transversally cut section in the transversal direction of the sheets. In figure 3 the hardness evolution after solution heat treatment at 470ºC at different oven times is shown.

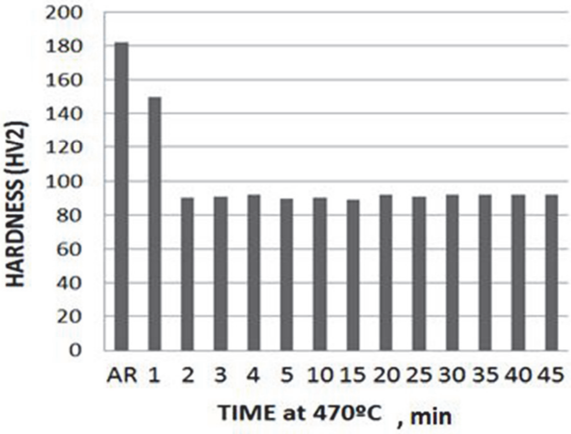

***Fig. 3**. Hardness after SHT at different oven times.*

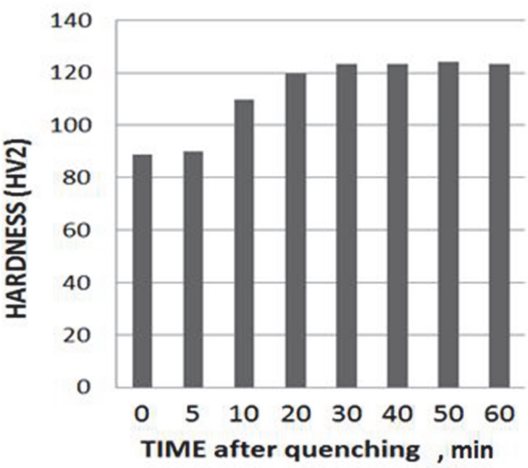

***Fig. 4**. Ageing after SHT.*

Each hardness data represents an average measurement of three through-thickness measurements from three different parts treated at the same conditions. Two minutes of oven are sufficient to reach the solution state since the sheet thickness is very small. On the other hand, ageing tests were also performed in order to define the maximum allowable time between the solution heat treatment and the forming of the part using same dimension samples and procedure. This is an important parameter for the press-shop since it defines if the material can be solution heat treated and stacked or must directly proceed to the forming operation. The samples were first solution heat treated at 470ºC and 5 min of oven time and water quenched. Hardness measurements were later performed just after and at different times after the quenching. In figure 4 the ageing behavior of the alloy is shown. It is observed that the material starts hardening at approximately 10 minutes being the maximum allowable time before forming small.

3.3. Uniaxial testing at different W-temper conditions

After the optimization of the solution heat treatment temperature and time, uniaxial tensile tests were performed from solution heat treated sheets. 100x20 mm samples were first solution heat treated at 470ºC and 5 minutes and subsequently water quenched. Just after the quenching, tensile samples were cut by mechanical shearing to guarantee a very fast preparation of the sample using a mechanical press. The specimens were cut following the ASTM E08 standard and using the sub-size specimen having 6 mm of calibrated width. To avoid ageing, the material was tested as soon as possible and always in less than 5 minutes to avoid hardening of the material. The test was repeated at least three times and the experimental work was completed testing the as-received material using the same procedure but air cooling the sample after the solution heat treatment.

This last test was performed to verify the reliability of this approach at an industrial environment and to avoid the water cooling step. The flow curve of the as-received material at T6 state and the solution heat treated and water quenched and air cooled conditions are shown in figure 5. The true fracture strain increases for the both solution heat treated conditions and the yield stress significantly decreases in comparison to the as-received material. The solution heat treated materials present a bigger strain hardening than the original material which is positive to increase the drawability. Among the solution heat treated materials, the water quenched one presents a bigger hardening than the air cooled one and the formability is bigger too. In comparison to the high temperature flow curves, the solution heat treated and water quenched material presents similar formability values to the one of 300ºC. Moreover, the strain hardening is bigger in these new conditions so it seems logical to think the formability of the W-temper approach will be more suitable than the warm forming one for components having deep walls and drawings.

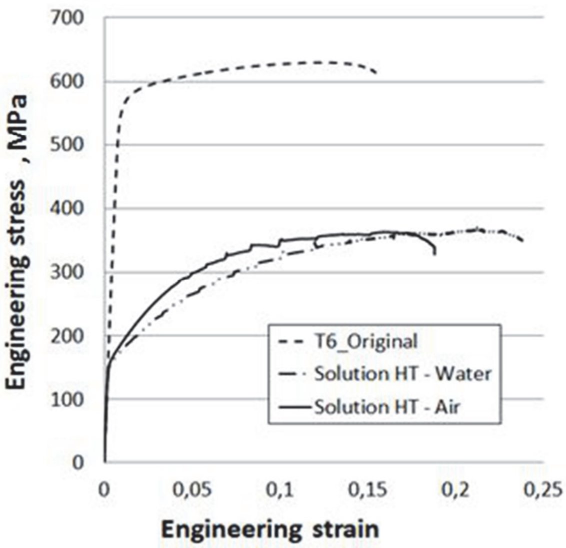

Fig. 5. Tensile tests of Solution Heat Treated sheets.

4. FORMING OF B-PILLAR

Finally, a real B-Pillar component was formed using an already available industrial tool to validate the different process variants (see figure 6). Three different approaches were tested: 1) forming of the part using the as received AW-7075-T6 material at room temperature, 2) forming of the part using the W-temper process and c) the hot forming of the as-received material. For the W-temper process, the solution heat treatment was realized at a temperature of 470ºC. The sheet was heated during 5 min before water quenching and the forming operation was performed just before the quenching. For the hot stamping process, an oven temperature of 500ºC was used since a temperature decrease of 50ºC - 75ºC was measured during the preheated sheet transport and the time needed from the position to the closing of the press. For both processes a Nabertherm 60/14 oven was used and air recirculation was used to ensure a good homogenization of the temperature along the sheet. The stamped B-Pillar parts are shown in figure 7.

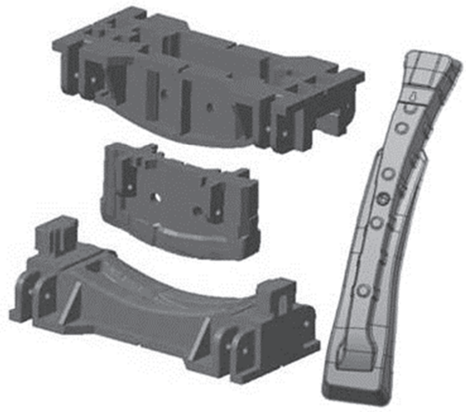

Fig. 6. B-Pillar tool and component.

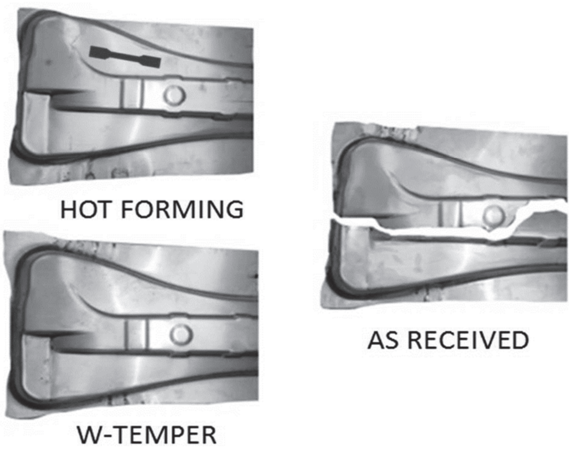

Fig. 7. Stamped B-Pillar parts.

Both hot stamping and W-temper strategies are valid to form a crack free and sound part. On the other hand a completely broken part is obtained using the as-received material at room temperature. Tensile test specimens were cut from the hot formed and W-temper formed B-Pillars to evaluate and compare the final properties of both forming strategies. Cutting area is shown in figure 7 where the specimen is colored in red. Additionally, a solution heat treated and air quenched part was also analyzed following the same approach although small crack were present in the deeper punch radii areas. The hot formed, w-tempered and air cooled specimens were subjected to an artificial heat treatment emulating an industrial e-coat process which was set to 160ºC and 20 minutes. Another two w-temper formed specimens were treated using an artificial e-coat process of 40 minutes and one hour to study the influence of this post forming step in the final component properties. All the flow curves of the formed and e-coated specimens are shown in figure 8. The graph clearly shows that is impossible to recover the initial as-received material properties. Solution heat treated and air cooled material presents much lower properties than the solution heated + water quenched ones and so it seems not to be a possible process route to be followed in final production. The hot formed and e-coated process and the W-temper and e-coated processes present similar yield strengths of about 340 MPa. The hot formed parts present a slightly higher Ultimate Tensile Strength and hardening and a bigger elongation at rupture (up to 23%) being a priori a better candidate for crashworthiness applications. Regarding the e-coating times, the one hour treatment specimen presents bigger yield strength than the e-coating of 20 minutes being the difference not very significant.

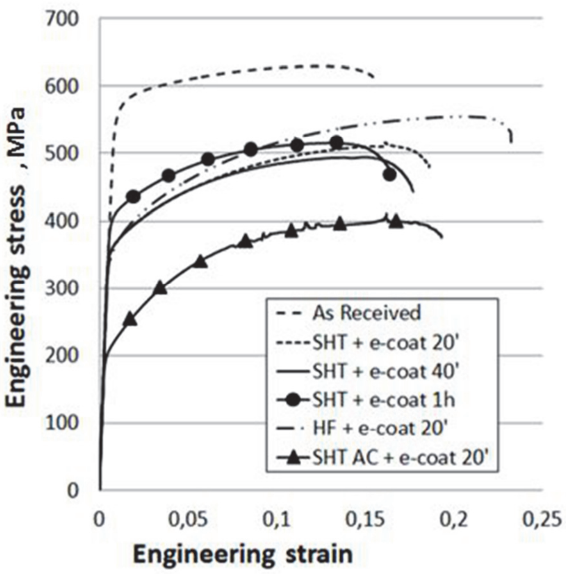

Fig. 8. Final properties of the stamped parts.

5. CONCLUSIONS

a) Tensile test results show that the AW-7075-T6 alloy is temperature and strain rate dependent. The YS and UTS decrease with increasing temperature. Strain hardening is negligible at high temperatures and could limit the drawability of deep parts where the material must be pulled form the blank holder areas to the forming zones.
b) The solution heat treatment and water quenching followed by subsequent direct forming, called as W-temper forming in this paper, seems to be a suitable strategy for forming high complexity industrial parts. A solution heat treatment temperature of 470ºC and treating time ranging from 2 to 5 minutes should be used to keep the process time cycle to the minimum.
c) Hot stamping and W-temper forming were applied for the stamping of an industrial B-Pillar with successful results. Final yield strength of the components after forming and e-coating is about 340 MPa. Although it is impossible to recover the initial as-received T6 condition material properties this values are well above the typical alloys used in the automotive industry, namely the 5xxx and 6xxx series alloys. At this stage, industrial manufacturers must evaluate the advantages and disadvantages of both processes and select the best one not only from the cost point of view but environmental impact, wear problems, etc. Further research is needed to compare both strategies using high deep wall components. The authors are currently conducting this work using a 100 mm spherical diameter LDR tooling.

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KSZTAŁTOWANIE STOPU ALUMINIUM AA7075 METODĄ W-TEMPER JAKO ALTERNATYWA DLA TŁOCZENIA NA CIEPŁO I GORĄCO

Streszczenie

Stopy aluminium, jak ważny, lekki materiał konstrukcyjny, są szeroko stosowane w przemyśle motoryzacyjnym i lotniczym. W ostatnich latach, wytwarzanie części o wysokich własnościach wytrzymałościowych i dużej precyzji stało się jednym z głównych celów zastosowań przemysłowych. Spośród dostępnych stopów aluminium, seria 7xxx jest szczególnie interesująca dla projektantów przemysłowych, ze względu na wysoką granicę plastyczności i wytrzymałość na rozciąganie. Jednakże, plastyczne kształtowanie tego typu stopów w warunkach przemysłowych, w temperaturze pokojowej jest bardzo ograniczone. Stąd prowadzonych jest wiele badań nad opracowaniem efektywnego kształtowania stopów aluminium w procesach na ciepło i gorąco z wykorzystaniem podgrzewanych narzędzi, mogących mieć zastosowania przemysłowe.

W niniejszej pracy analizowano proces kształtowania zwany W-temper jako alternatywę dla odkształcania na ciepło lub gorąco. Walidację nowego procesu wytwarzania przedstawiono dla wybranej, rzeczywistej części produkowanej dla przemysłu motoryzacyjnego, fragmentu słupka B. W ostatniej części pracy omówiono końcowe własności mechaniczne produktu, gdzie kształtowanie typu W-temper zostało porównane z procesem tłoczenia na gorąco.

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