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STAMPING AN AA5754 TRAIN WINDOW PANEL WITH HIGH DENT RESISTANCE USING LOCALLY ANNEALED BLANKS

A. Piccininni①, **P. Guglielmi**①, **A. Lo Franco**② **and G. Palumbo**①

①DMMM - Politecnico di Bari
Viale Japigia 182, Bari 70126, Italy
e-mail: gianfranco.palumbo@poliba.it, Web page: www.poliba.it
②O.Me.R. spa
Via Angelo Russello 1, Carini (Pa) 90044, Italy
e-mail: a.lofranco@omerspa.com, Web page: omerspa.com/

Abstract. The warm stamping of an AA5754-H32 window panel for railway vehicles applications has been proposed in the present work. The adoption of increased working temperatures can be surely considered the most effective solution for this alloy to overcome the limited material formability at room temperature [*Palumbo et al. "Warm Forming of an AA5754 Component for Railway Vehicle Applications", Procedia Engineering, Vol. 183, 2017, Pages 351–356*] but, in order to improve the overall dent resistance of the component, the initial wrought conditions have been chosen in the present work. The manufacturing of the window panel was thus subdivided into a preliminary local heat treatment (assumed to be performed by laser) to anneal the material and a subsequent warm stamping step using heated tools. The best combination of temperature and holding time able to produce the annealing of the investigated alloy was determined using the physical simulator Gleeble 3180. On the contrary, the warm forming step was designed by means of thermo-mechanical simulations: in order to model the AA5754-H32 blank with annealed regions, an extensive experimental campaign (tensile and formability tests) was conducted using specimens in the annealed (H111) and in the wrought (H32) conditions. Through the numerical approach it was thus possible define: (i) the extent of the annealed regions; (ii) the punch speed to get a sound component.

1. Introduction

In the last 5 years, railway vehicles are gaining an important role in the panorama of the mass transportation [1]: such increasing demand needs to be supported by improving the overall quality of the vehicles in terms of safety, structural properties, mass and harmful emissions. The research for the most suitable material able to match all the above mentioned requirements is not trivial and still remains an open question. Aluminium (Al) alloys are surely good candidates, being able to provide a high level of the strength-to-weight ratio and being characterized by superior properties in terms of fire protection (in case of fire, differently from plastics or composites, Al alloys do not produce smoke [2]). The positive aspects of Al alloys are partially counterbalanced by the poor formability at room temperature, which limits the possibility of producing complex components and/or determines the need of a multiple-steps manufacturing process. It should also be pointed out that several studies available in literature report the

beneficial effect of working temperatures higher than the room one on the formability [3]: the increased limit strains the material can experience before the onset of necking when working in warm conditions appreciably improve the Limit Drawing Ratio [4] and, as a consequence, make the manufacturing of complex components possible [5].
The present work deals with the warm stamping of an AA5754-H32 window panel for railway vehicles applications: since the alloy in wrought condition was chosen to increase the final quality of the material in terms of dent resistance (it is related to the material yielding point [6,7]), the manufacturing of the window panel was subdivided into a preliminary local heat treatment (assumed to be performed by laser) to anneal the material and a subsequent warm stamping step using heated tools. The best combination of temperature and holding time able to produce the annealing of the investigated alloy was determined using the physical simulator Gleeble 3180. On the contrary, the warm forming step was designed by means of thermo-mechanical simulations: in order to model the AA5754-H32 blank with annealed regions, an extensive experimental campaign (tensile and formability tests) was conducted using specimens in the annealed (H111) and in the wrought (H32) conditions. Through the numerical approach it was thus possible define: (i) the extent of the annealed regions; (ii) the punch speed to get a sound component.

2. Warm stamping of the window panel

The component to be produced is the inner window panel (dimensions: 2000 mm x 1300 mm x 2 mm) shown in Figure 1: the regions highlighted are the most critical, where rupture occurs if working at room temperature.

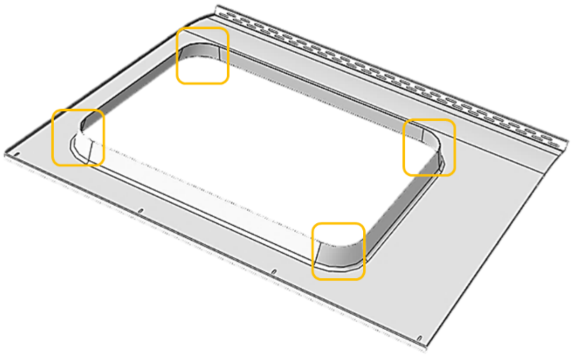


Figure 1 The case study

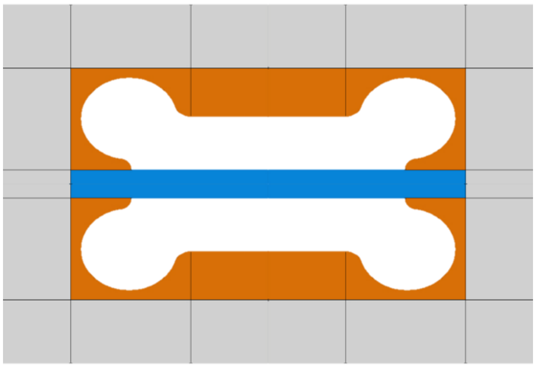


Figure 2 The adopted initial blank geometry

In order to improve both the material draw-in and the contact with the (heated) punch during the stamping, the initial blank geometry proposed in Figure 2 was thus adopted [3].

3. Material characterization

The annealing process of specimens in wrought condition (H32), 2 mm thick, was physically simulated by means of the Gleeble 3180 system. The specimen, clamped between two cooled jaws, was heated by Joule effect (the current was modulated according to temperature data from a thermocouple welded in the middle of the specimen): a parabolic temperature profile was thus determined along the specimen. Different levels of both the test temperature and the holding time were investigated; in addition, also different heating rates (*HR*) were adopted. Figure 3 resumes the results of the annealing tests in terms of hardness profiles along the specimens.

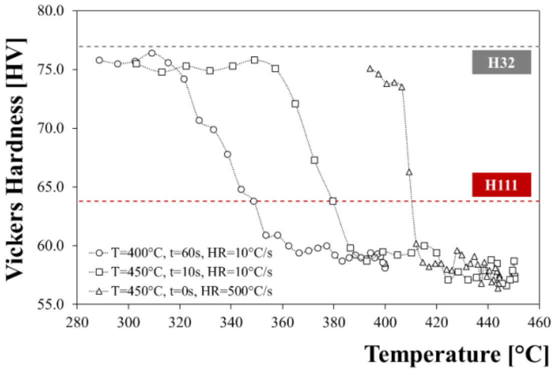


Figure 3 Hardness profiles along the specimens tested using the Gleeble system

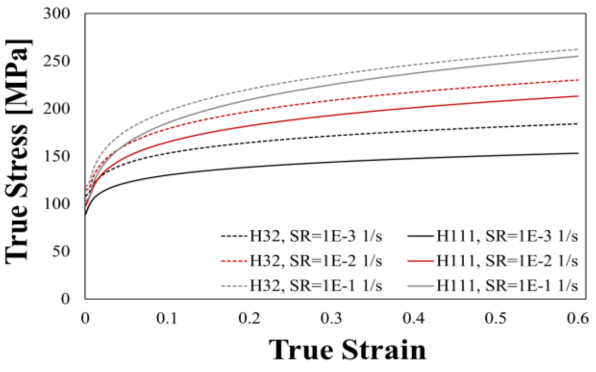


Figure 4 Flow stress curves (H32 and H111) at 200°C at the investigated strain rates

If considering a conventional conductive heating (setting the heating rate equal to 10°C/s), at 350°C, a holding time of 60 s allowed to completely anneal the material (dotted curve with circular markers); if the temperature of the annealing treatment increased up to about 380°C, a correspondent decrease in the holding time was detected (dotted curve with square markers). The physical simulation of the annealing treatment by laser, characterised by the highest heating rate, revealed that almost no holding time was necessary if the material was heated up to 410°C (dotted curve with triangle markers).

3.1. Tensile tests

The mechanical behavior in warm condition was assessed by means of tensile tests using the same Gleeble system: 3 levels of both the temperature (150, 200 and 250°C) and the strain rate (0.001, 0.01 and 0.1 s^{-1}) were investigated (3 replications for each condition). Flow stress curves were obtained fitting experimental data by means of the Hollomon power law (an example is shown in Figure 4).

3.2. Formability tests

Nakajima tests were conducted to assess the material formability in the annealed state (H111), both at room temperature and at the same temperature levels investigated in the tensile tests; in addition, 3 different punch speeds were tested. Limit strains were calculated according to the International Standard [8] and a total number of 6 specimen geometries was adopted for evaluating the Forming Limit Curves (FLCs). In Figure 5 the remarkable effect of both the temperature and the strain rate on the limit strain in plane strain condition (FLD_0) has been plotted.

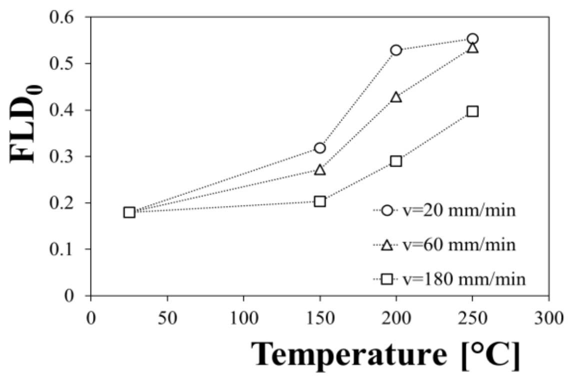


Figure 5 Effect of temperature and strain rate on the limit strain in plane strain condition

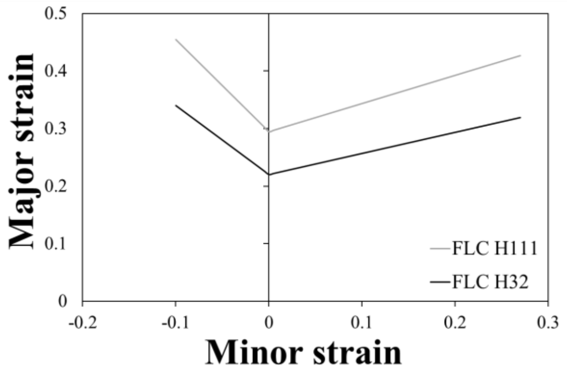


Figure 6 Analytically determined FLC in wrought condition (T=150°C, SR=0.001 s^{-1})

Experimental results revealed that the formability improved when the working temperature was increased, whereas if the strain rate (i.e. the punch speed) was increased a remarkable reduction of the material formability was measured. On the contrary, FLCs in wrought conditions (H32) were analytically determined from the ones in the annealed state. In particular, since the elongation at necking can be well described by the strain hardening coefficient (*n*) while the post-necking behaviour can be well related to the strain rate sensitivity index (*m*) [9], the elongation at fracture (i.e. the ductility of the alloy) has been assumed as proportional to the abovementioned quantities. The reduction of the material formability (*R* in equation 1) has been assumed in this work equal to the reduction of the elongation at fracture which, in turn, has been calculated using the eq. 1:

$$R=\frac{(\varepsilon_f)_{H32}}{(\varepsilon_f)_{H111}}\propto\frac{(n+m)_{H32}}{(n+m)_{H111}} \tag{1}$$

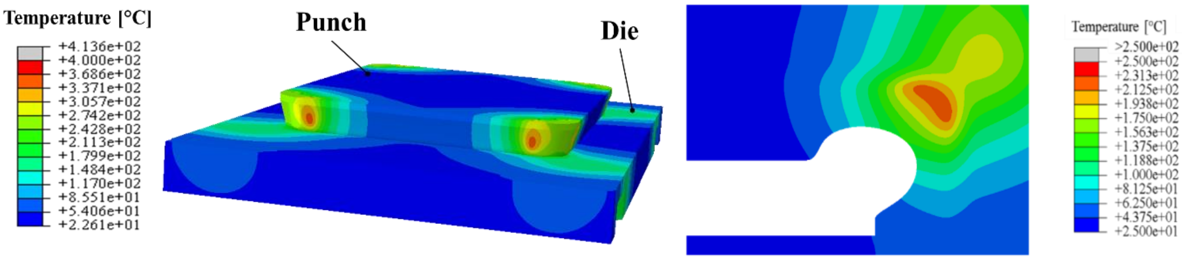
The parameter R has been thus used to shift the FLC in the annealed state: Figure 6 shows, for example, the comparison between the experimentally determined FLC (H111, bold grey line) and the one determined for the H32 condition using the abovementioned approach (bold black line) at the temperature of 150°C and at the equivalent strain rate of 0.001 s^{-1}.

4. Finite Element Model: warm forming of the window panel

Due to the large number of the involved parameters, uncoupled thermo-mechanical FE simulations were used to design the stamping process. In the present work, both for the thermal step and the subsequent warm forming simulation, only a quarter of the whole system was taken into account to limit computational costs.

4.1. Steady-state thermal analysis

Preliminary thermal steady-state simulations were run changing the number and the power of the electric cartridges adopted in the punch and in the die. Figure 7 shows the optimal temperature distributions on both the stamping tools (a) and the blank (b), obtained adopting 2 electric cartridges in the die and 2 in the punch, which revealed to give the best compromise between the material formability and the maximum working temperature in the regions close to the heating devices.



(a) (b)

Figure 7 Temperature distribution on the heated stamping tools (a) and on the blank (b) using the optimal configuration of the electric cartridges

In fact, from Figure 7b it can be noted that the deformation zone of the blank resulted to be about 250°C (at which the material exhibited a considerable formability improvement) and, at the same time, the maximum temperature in the stamping tools (414°C) was lower than the critical value (650°C).

4.2. Forming step simulations

The temperature distribution obtained from the thermal simulation using the optimal heating configuration was imported as a predefined temperature field into the explicit mechanical model to perform the subsequent stamping step. Tools (punch, die and blankholder) were modelled as rigid bodied (mesh size: 30 mm), while the blank was modelled as a deformable body (mesh size: 4 mm; through-thickness integration points: 5). In order to further reduce computational costs, the mass scaling was also adopted in these simulations. A damage criterion based on the previously calculated FLCs (both in the annealed and in wrought conditions) was implemented.

Warm forming simulations were run changing both the extent of the Laser Heat-Treated region and the punch speed. In particular, the two configurations shown in Figure 8 (LHT#1 and LHT#2) were investigated, while the punch speed was varied on 3 different levels (20, 60 and 180 mm/min), being such values the same adopted for formability tests.

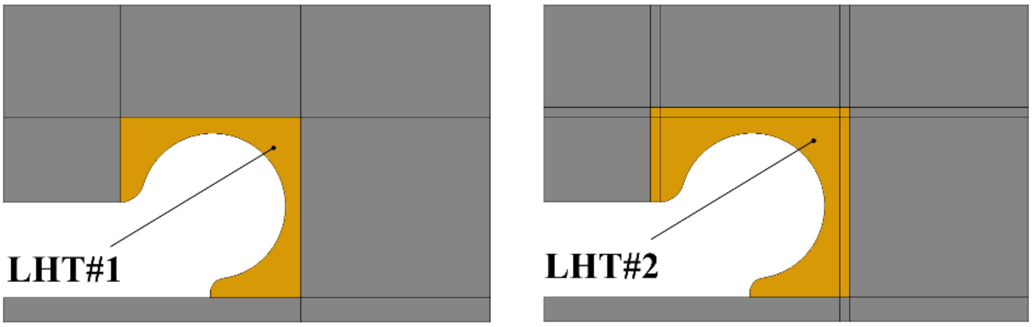


Figure 8 The two investigated Laser Heat-Treated (LHT) regions

The output variable FLDCRT [10], which quantifies the severity of the nodal strain condition computing its distance from the FLC, was used to assess the feasibility of the investigated configurations. As an example, the FLDCRT contour map concerning the simulation conducted setting the highest punch speed (180 mm/min) and using the region LHT#1 has been shown in Figure 9: nodal strain overcomes the forming limit in the blank portion highlighted in grey (FLDCRT>1), thus predicting the rupture in the critical area.

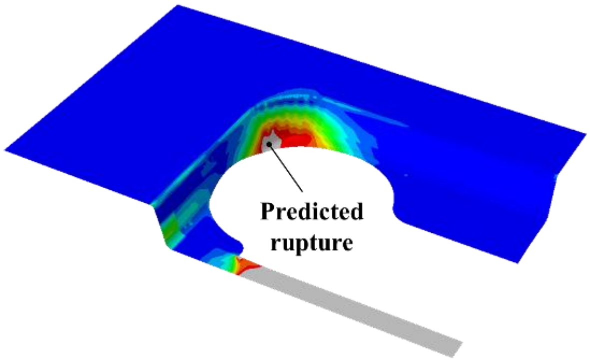


Figure 9 FLDCRT contour map (LHT#1, v=180mm/min)

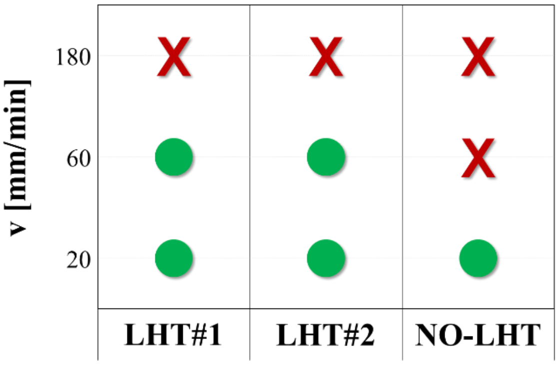


Figure 10 Summary of results from numerical simulations changing the extent of the annealed region and the punch speed

A summary of the results is proposed in Figure 10: green circle indicates a sound component, while the red cross a rupture. For comparison purposes, also the warm stamping of the window panel without any preliminary laser heat treatment was simulated.

It can be seen that when the punch speed was too high (180 mm/min), the rupture could never be avoided. On the contrary, when the lowest punch speed (20 mm/min) was set, the improved alloy formability led to a successful stamping, making the preliminary laser heat treatment not anymore necessary; in this case the beneficial effect of the improved formability was partially counterbalanced by the increase of the cycle time. The advantage of the preliminary laser heat treatment was evident when setting the punch speed to the value of 60 mm/min: in fact, a sound component could be predicted only if the local annealing in the critical areas was preliminary performed; by adopting such an approach, a sensible reduction of the cycle time could be obtained.

5. Conclusions

In the present work, the manufacturing of an AA5754 window panel for railway applications, characterised by high dent resistance, has been numerically investigated. Since a blank in wrought conditions (H32) was adopted to improve the final quality of the window panel, the process was divided into a preliminary laser heat treatment (to selectively anneal the blank in the critical regions) and a subsequent warm forming step.

Physical simulation experiments using a Gleeble machine allowed to evaluate both the temperature and the time to be imposed on critical regions of the blank (i.e. where ruptures occurred in the blank during the standard cold stamping) in order to make them annealed.

The blank with annealed (H111) regions was thus used for simulating the warm stamping process: both the extent of such heat-treated regions and the punch speed were investigated using a thermo-mechanical approach (the temperature field from thermal simulations was imported in the mechanical analysis and the occurrence of rupture was predicted using a Forming Limit Diagram based damage criterion).

Numerical simulations implementing the mechanical and deformative material (assessed through tensile and formability tests, both in warm conditions) revealed that, in order to reduce the cycle time, the proposed approach based on a preliminary laser heat treatment in critical areas followed by the warm stamping is necessary.

In addition, it was demonstrated that the punch speed plays a key role in the stamping of the investigated Al alloy: it resulted feasible to manufacture a sound component, even without any preliminary laser heat treatment, only when a remarkably decrease of the punch speed (down to 20 mm/min) was adopted.

References

[1] Eurostat, Railway passenger transport statistics - quarterly and annual data, (2016).
[2] DIN EN 45545-2, Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behaviour of materials and components (includes Amendment A1:2015), (2016). http://www.en-standard.eu/din-en-45545-2-railway-applications-fire-protection-on-railway-vehicles-part-2-requirements-for-fire-behaviour-of-materials-and-components/.
[3] G. Palumbo, A. Piccininni, P. Guglielmi, R. Spina, L. Tricarico, D. Sorgente, et al., Warm Forming of an AA5754 Component for Railway Vehicle Applications, Procedia Eng. 183 (2017) 351–356. doi:10.1016/j.proeng.2017.04.051.
[4] G. Palumbo, L. Tricarico, Numerical and experimental investigations on the Warm Deep Drawing process of circular aluminum alloy specimens, J. Mater. Process. Technol. 184 (2007) 115–123. doi:10.1016/j.jmatprotec.2006.11.024.
[5] G. Palumbo, A. Piccininni, Numerical-experimental investigations on the manufacturing of an aluminium bipolar plate for proton exchange membrane fuel cells by warm hydroforming, Int. J. Adv. Manuf. Technol. 69 (2013) 731–742. doi:10.1007/s00170-013-5047-1.
[6] G. Ekstrand, N. Asnafi, On testing of the stiffness and the dent resistance of autobody panels, Mater. Des. 19 (1998) 145–156. doi:Doi: 10.1016/s0261-3069(98)00028-4.
[7] S. Holmberg, P. Thilderkvist, Influence of material properties and stamping conditions on the stiffness and static dent resistance of automotive panels, Mater. Des. 23 (2002) 681–691. doi:10.1016/S0261-3069(02)00079-1.
[8] 12004-2 ISO, Metallic materials - Sheet and strip - Determination of forming-limit curves - Part 2: Determination of forming-limit curves in the laboratory, 2008.
[9] M. Aghaie-Khafri, R. Mahmudi, Flow localization and plastic instability during the tensile deformation of Al alloy sheet, Jom. 50 (1998) 50–52. doi:10.1007/s11837-998-0287-5.
[10] Dassault Systems, User Manual, Abaqus (6.12), 2012.