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An emerging manufacturing route for the fabrication of Al-based complex railway interiors at room temperature

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Abstract

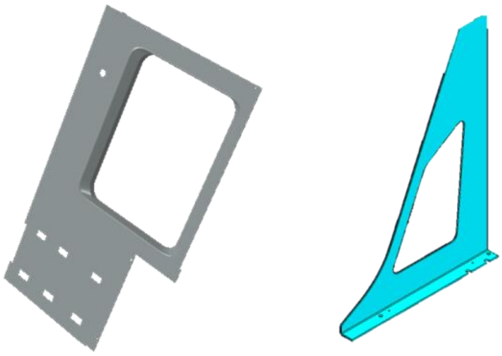
In the present work, an emerging manufacturing route to enhance the poor formability of Aluminium (Al) alloys at room temperature is investigated and applied to two different industrial sheet metal components, both made of AA5754 initially purchased in wrought conditions (H32). The approach was based on splitting the manufacturing processes into two separate moments: at first, the blank was subjected to local short-term heat treatments (to bring the material in the more formable annealed H111 condition) and, once cooled down, formed at room temperature. After the preliminary characterization of the alloy in both the conditions (H32 and H111), based on tensile tests and forming limit curves, the two abovementioned steps were numerically designed by means of the Finite Element (FE) commercial code Abaqus/CAE. In particular, the local heating step was simulated in order to define the best combination of time and temperature to bring locally the material in the annealed H111 state. The resulting distribution of properties was then imported in a second numerical model where the parameters of the forming operations were numerically set to avoid the blank rupture and obtain the two components, i.e. the window panel via sheet stamping and the bicycle rack via sheet bending. The numerical results, in terms of

heating strategies and forming setup, were eventually validated by means of experimental trials and both the components were correctly manufactured.

Keywords: aluminium, lightweighting, formability, locally annealed blanks, FEM, sheet metal forming.

1 Introduction

The continuous demand for lower polluting emissions and energy consumption in the railway transport sector has moved the attention on the research for effective solutions to reduce the vehicle masses [1]: resin-based and/or fiber reinforced plastic components were originally considered suitable candidate [2], but they were lacking of safety performance. Therefore, the Aluminium (Al) alloys have recently gained more visibility not only thanks to their high strength-to-weight ratio, but also to the outstanding fire/smoke resistance as reported by the DIN EN 45545-2 standard. Nevertheless, it's well known that those advantages are partially counterbalanced by the poor formability at room temperature if compared to a mild steel grade for drawing applications [3]. As a consequence, the scientific community put huge efforts in researching promising solutions to overcome such limitations: from one side, the increase of the working temperature – i.e. the basic principle of all the warm/hot forming process – has shown remarkable results in improving the achievable complexity in one-step processing [4–7]. An alternative innovative route splits the manufacturing into two separate sub-steps: at first, the material is subjected to a short-term heat treatment to locally alter the properties in the most critical points according to the geometry to be obtained. Then, the locally-altered blank can be formed at room temperature, thus using less complex equipment [8–10]. Such an innovative route, that can be identified as the heating-before-forming (HBF) approach, has been deepened within the framework of the 4-years research project FOR.TRA.IN. (acronym for "FORming of complex component for the railway TRAnsportation sector with INtegrated local heat treatment") funded by the Italian Ministry of Economic Development and jointly carried out by the Politecnico di Bari and the O.Me.R. company, leading the market of the interiors for railway applications. The research project underlined the strong intention of the O.Me.R. company to widen its product portfolio, enlarging its capabilities of producing complex components by means of innovative technologies. Therefore, the main goal of the project was the definitive implementation of the HBF route within the industrial environment. The attention was, in fact, focused on two different case studies: a window panel (Figure 1a), to be manufactured via stamping at room temperature, and a bicycle rack (Figure 1b), to be manufactured by sheet bending at room temperature. Both the products are made of the AA5754 strain-hardenable Al alloy.



a) b)

Figure 1 The investigated case studies: a) the window panel, b) the bicycle rack

2 Methods

The process design was based on a predefined sequence of steps depicted in Figure 2.

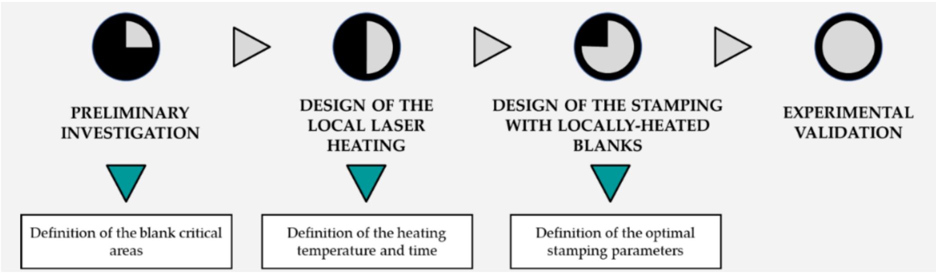
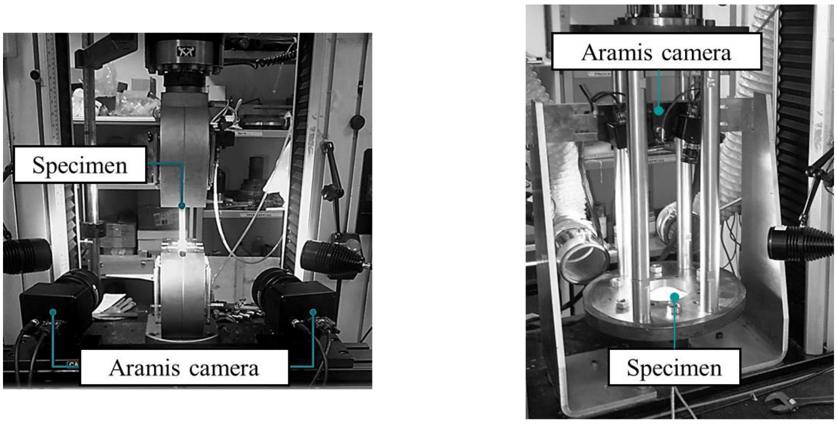


Figure 2 Map of the proposed methodology

The number of parameters involved in the process led to the adoption of a Finite Element (FE) approach. The AA5754 was characterized in the H32 and the H11 conditions. Tensile tests were carried out to determine the flow curves (Figure 3a), whereas formability tests provided the forming limit curves (Figure 3b).



a) b)

Figure 3 AA5754 characterization: a) flow curves and b) forming limit curves (FLC) at room temperature

The tools used for the forming operations were modelled with Abaqus/CAE as rigid bodies whereas the blank as a deformable one. Preliminary FE simulations, for both the case studies, were run modelling the blank in the H32 conditions and the most critic regions (occurrence of rupture) were identified thanks to the activation of a damage criterion able to evaluate the distance between the actual nodal strain and the material FLC. Once identified the region where the local heating had to be carried out, thermal simulations were run considering, according to the extent of the area to be treated, one of the two heating solutions equipping the Prototype Flexible Unit (PFU). The simulation of the local heating was fundamental to evaluate the best combination of temperature and time to effectively bring the material from the initial H32 to the H111 condition. The forming step was simulated again modelling the blank with the optimized distribution of properties and the parameters optimized to obtain a sound component. The experimental validation was carried out on the PFU, composed of two adjacent sub-units, a Gigant 630-tons hydraulic press machine (A in Figure 4a) and the local heat treatment sub-unit (B in Figure 4a).

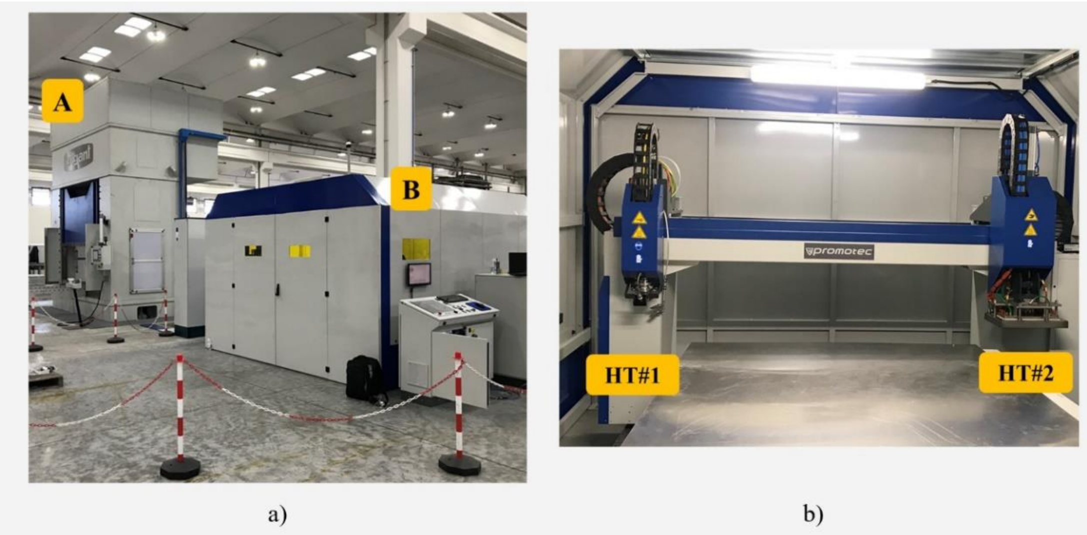


Figure 4 The Prototype Flexible Unit (PFU): a) the two sub-units; b) the local heating sub-unit

The local heating sub-unit is equipped by a 1 kW diode laser (HT#1 in Figure 4a) and a conductive plate (HT#2 in Figure 4b) with eight 400 W cartridges.

The local heating of the blank could be carried out choosing one of the two solutions according to the dimension of the initial blank and the extent of the area to be treated. Experimental trials were carried out to validate the numerical predictions: heat treatments were performed setting the time and temperature levels defined by the thermal analyses and, subsequently, the pre-treated blank were formed at room temperature.

3 Results

The proposed methodology was applied for the manufacturing of two industrial case studies: a large window panel and a bicycle rack. As for the former, results in terms of numerical simulations are depicted in Figure 5.

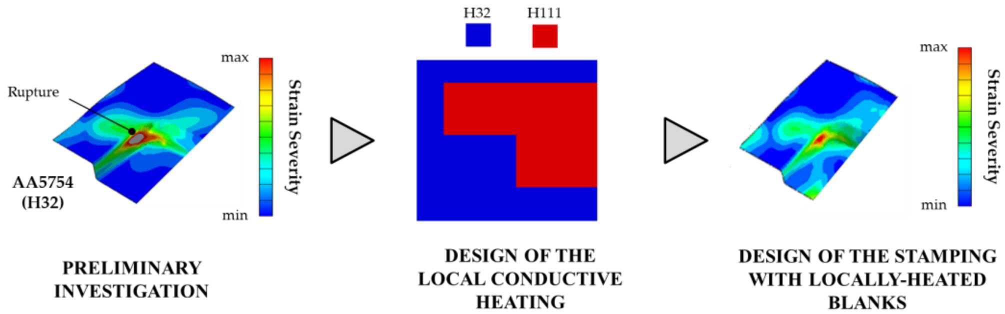


Figure 5 FE process design of the window panel

Thanks to the implementation of the FLC in the H32 state, preliminary analyses predicted the blank rupture in the corner regions (highlighted in grey, contour map on the left), where the nodal strain levels overcame the limit condition. Therefore, the blank portions where the formability had to be enhanced were easily determined. Due to the dimensions of the case study and the extent of the portion to be modified, the conductive heating was chosen as suitable solution to locally bring the critic regions to the fully annealed state (H111). The heat treatment in terms of temperature and holding time was designed by means of thermal simulations and the sequence of heating steps subsequently optimized in order to properly confine the treated portion and avoid excessive heat dissipation in the adjacent portions of the blank. The resulting properties distribution was imported in the subsequent numerical model for the simulation of the stamping using a locally treated blank: it was then demonstrated that, beside a proper definition of the stamping parameters, an optimized distribution of properties led to the absence of any predicted rupture and to the manufacturing of a sound component.

Similar results were obtained applying the proposed methodology to the second case study: the bicycle rack. According to the geometry constraints, the designed bending radius was smaller than the limit prescribed by the standard [11] for the investigated material in the as-received conditions (H32). As shown in Figure 6, preliminary bending simulations showed a more severe strain condition (rupture was predicted) over the bending line in absence of any localized heating. Due to the more limited extent of the area to be treated, the local laser heating was chosen as the most suitable solution and simulated to optimize its parameter and achieve the desired distribution of properties. Such distribution, once imported over the blank for the further bending simulation, once again confirmed that the enhancement of the formability limits over the bending line (the material was brought to H111 the annealed state) the bending limits at room temperature could be easily overcome.

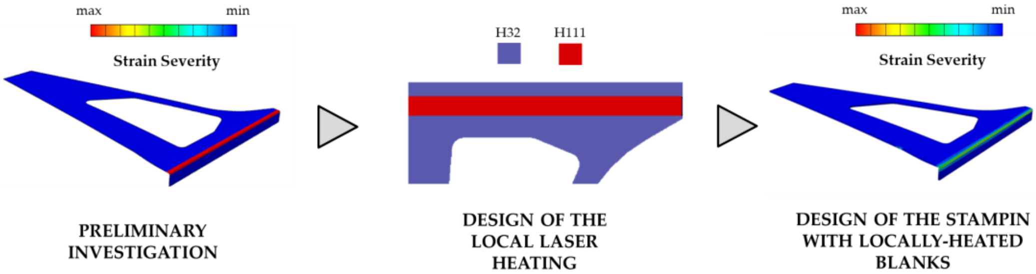


Figure 6 FE process design of the bicycle rack

4 Conclusions and Contributions

The FE design of the complex manufacturing route was eventually validated by experimental trials on both the investigated case studies.

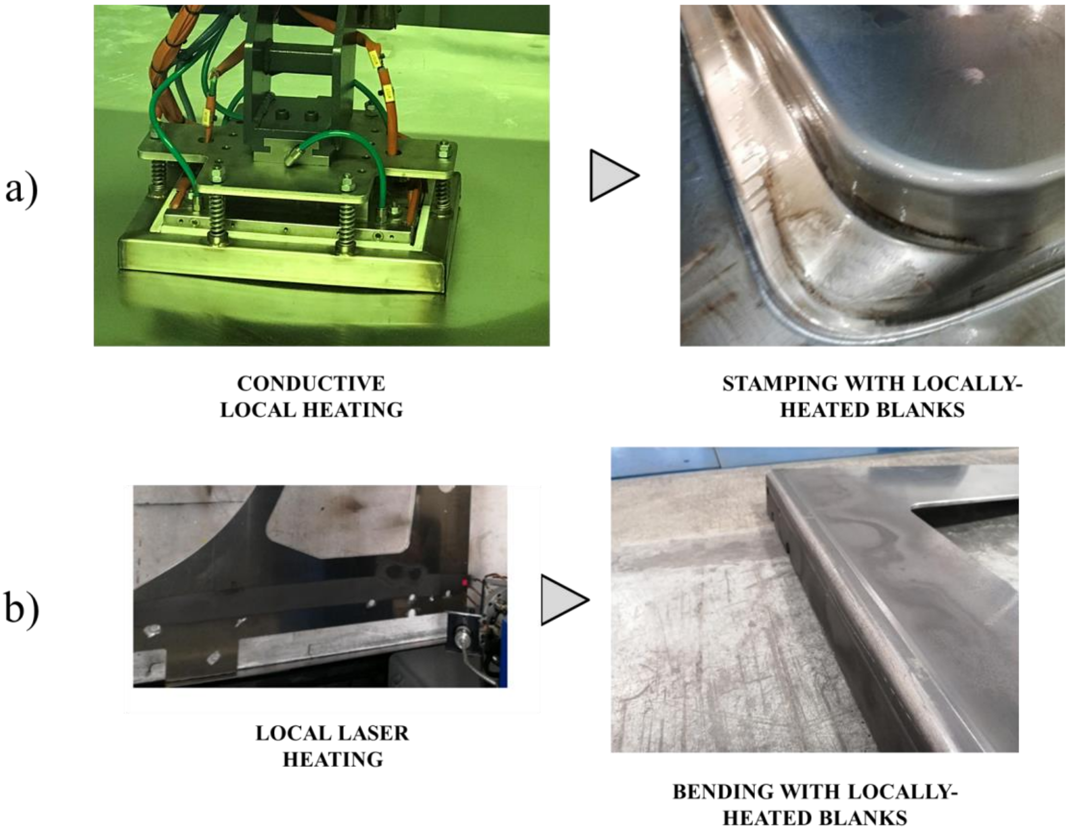


Figure 7 Validation of the manufacturing routes: a) window panel, b) bicycle rack

Figure 7 shows the two steps composing the proposed methodology: the local heating was carried out, according to the results of the FE thermal analysis, using the suitable heating technology according to the extent of the region to be altered (in the case of the laser heating, the blank was preliminarily coated with graphite spray to increase the absorption of the light radiation). The subsequent forming operation, carried out at room temperature, led to the manufacturing of a sound component for both the case studies: the proper alteration of the material properties from the initial state improved the material formability preventing the rupture in the corner regions of the blank (see Figure 7a) and in the bending line of the bicycle rack (Figure 7b).

The proposed manufacturing route represents a promising solution to overcome the poor formability of aluminium alloys at room temperature making possible the achievement of complex geometries without needing the manufacturing of subparts and their subsequent joining. The designed Prototype Flexible Unit embodies the flexibility of the manufacturing route, especially in terms of available solutions for the local heating. In fact, the conductive heating was considered to anneal a wider portion of the blank in the case of the window panel manufacturing, whereas the laser heating was chosen when a limited portion of the bycicle rack has to be annealed to increase the bending angle. The versatility of the manufacturing routes lies also in its capability of processing a wide span of materials: with a particular focus on the aluminium alloys, the present paper has demonstrated the potentialities of the local heating acting as a selective annealing "tool" when applied to the AA5754 strain-hardenable Al alloy. But, as also reported in literature, the local heating can be equally applied to the age-hardenable Al alloys (i.e. the 6xxx series) and tailor the mechanics regulating the dissolution of precipitates of promoting their appearance at the grain boundaries. Moreover, the experimental validation confirmed the effectiveness of the proposed methodology within the an industrial environment with a subsequent increase of its TRL.

Acknowledgements

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