Semisolid forging of 250 automotive spindles of S48C steel

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Keywords: Steel, Semisolid Forging, Tooling, Automotive, Industry

Abstract Nowadays, globalisation enables a rapid uptake of the classical manufacturing technologies. In order to remain competitive and fulfil the global trend of reduction of emissions, innovative production processes that reduce the energy and raw material consumption should arise. Semisolid forging (SSF) is one of those techniques with great potential to fulfil those requirements maintaining the high quality of the components. Thus, the objective of this work is twofold: to produce a complex geometry part saving material and energy using the off-the-shelf S48C steel grade, and to demonstrate the capability of the process to produce a pre-series of 250 components without excessive tooling damage.

Introduction

In the actual industrial framework with the current trend in prices of raw material and their sources, near net shaping of mechanical components can be a key factor to get the desired competitiveness. SSF is one of those techniques that exhibit near net shape capabilities. It presents high potential for manufacturing steel components whilst saving material and energy and, indeed, it is suitable for working with high melting point alloys like steels.

Since its discovery by Spencer et al [1] in the early 70’s, most of the efforts were focused on low melting point alloys (mainly on aluminium) [2]. These investigations made possible the industrialization of several components [3,4]. The first steel components manufactured using the SSF technology were undertaken in 1992 in Sheffield [5]. Nevertheless, despite the attempts of many researchers to introduce it to industry [6,7], no industrialization is known yet. In any case, great developments have been made in recent years. To date, some off-the-shelf low [8], medium [9,10] and high [11] carbon steel alloys have been successfully manufactured by SSF. Moreover, the tool wear, one of the main problems of this technology, does not seem to be so critical as more than 6000 components have been manufactured without any discernible tooling damage by Bigot et al [12].

Mondragon Unibertsitatea was also capable of manufacturing sound automotive spindles of 2.8 kg using commercially available 42CrMo4 [9] and S48C [10]. A 20\% raw material saving was achieved while the forming steps were reduced to a unique one. This implies a direct energy saving since the required forming loads are reduced 6 to 8 times in comparison with hot forging (HTF). However, the amount of produced components was not big enough to validate the process. Therefore, this work will be focused on manufacturing a pre-series of 250 components with a new automotive spindle geometry using S48C steel grade.

New automotive spindle design

The selected component is a commercially available automotive spindle of around 2.3kg (Fig. 1(a)). The spindle can be found in the suspension system of the car being the responsible for attaching the wheel assembly to the vehicle. In comparison with the previous geometry (Fig. 1(b)), a larger
material flow through a thinner cross section in the perpendicular to the axle direction is required to fill the cavity. This will mean higher filling complexity and larger wear on the tooling. According to EN 10243-1, this geometry corresponds to a very complex shape.

![Figure 1](image)

Figure 1-New (a) and old (b) spindle geometries.

Except machining allowance reduction there are not any geometry modifications in comparison with the HTF component in order to have a direct relation and to observe how the damage of the tooling evolves. The active tooling consists of a punch and upper and lower dies. Their design is based on the component’s geometry, the process and the SSF cell requirements.

Material

The S48C steel grade, also known as 1.1191 or CK45, is a medium carbon steel grade commonly used in automotive industry for shaft, gears and differentials manufacturing. SIDENOR supplied the material in round bars of 65 mm of diameter after hot rolling. Therefore, the material was not especially prepared for SSF. Its composition is given in Table 1. In the Figure 2 a homogeneous ferrite-pearlite structure with similar grain size in the different areas of the initial billet can be observed. The solidus and liquidus temperatures of this material are 1400°C and 1498°C respectively. The evolution of liquid against temperature is shown in Figure 3.

![Table 1](image)

Table 1- Chemical composition of S48C steel grade (in wt.%).

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
</tr>
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<tbody>
<tr>
<td>0,48</td>
<td>0,82</td>
<td>0,27</td>
<td>0,019</td>
<td>0,024</td>
<td>0,16</td>
<td>0,15</td>
<td>0,21</td>
</tr>
</tbody>
</table>

![Figure 2](image)

Figure 2- Micrographs of S48C steel grade in the as-supplied state in the surface (a), medium length (b) and centre (c) respectively. Scale bar: 400 µm.
Figure 3- DSC results (a) and calculated liquid fraction against temperature (b).

SSF manufacturing cell and process

The component’s manufacturing has been performed using the SSF cell in Mondragon Unibertsitatea [13] (Fig. 4(b)). It consisted of a 150 kW and 1.7-3 kHz vertical EFD induction heating equipment, a six axis KUKA handling robot with a self-designed grip and a 400 tons FAGOR servo-mechanical press [14]. To ensure a proper punch movement and die closing and opening, a self-designed tooling was used (Fig. 4(a)). For a more detailed explanation about the cell and tooling go to [15].

Figure 4- The self-designed tooling (a) and the SSF cell (b) of Mondragon Unibertsitatea.

The manufacturing process can be divided into the following 5 steps:

Induction heating. The heating cycle consists of several steps to ensure a quite homogeneous temperature through the billet. Furthermore, to get a homogeneous and stable temperature on the different elements in the furnace it was necessary the performance of five dummy heating cycles. The heating set up has been designed to obtain a 5% of liquid fraction.

Handling. Once the heating finishes, the robot takes the semisolid billet and places it into the tooling.

SSF: The robot comes out from the press and triggers the forming step. The ram and the punch move fast from the upper to the lower position staying there for five seconds to continue pressing the material. Note that the ram speed is not constant during the movement due to the press type. In any case, the deformation starts at 300 mm/s. Finally, it comes back to the initial position.
**Component ejection.** After retracting the clamping system, the tooling is opened letting the ejection system of the press to take out the manufactured component.

**Cleaning and lubrication.** Cleaning and lubrication processes are performed manually. CeraSpray® ceramic lubricant is used as suggested by Pierret et al [16].

**Results**

**SSF of 250 components.** All the components have been successfully manufactured by SSF (Fig. 5(a)). The process consisted of a unique forming step in comparison to the three steps plus a flash removal operation of the conventional HTF (Fig. 5(b)). Due to the near-net-shape nature of the SSF, which allows flash elimination and reduction of machining allowances, raw material is reduced in an 18%. Thus, taking into account the whole process chain, the component’s cost reduction is estimated to be 9.69 %.

The average maximum press load registered during the forming step was 280 tons, nearly 8 times less than the maximum load measured in classical HTF.

![Figure 5](image)

**Figure 5-** Part of the manufactured batch (a), differences between HTF and SSF (b).

The component’s geometry is successfully filled apart from some imperfections in the edges due to CeraSpray® entrapment (Fig. 6(a)). This can be easily overcome by machining some escape holes in the dies. In any case, those imperfections do not represent any problem for component’s mechanical performance. During filling, material’s front is really smooth and does not show any grain decohesion or burning. In conclusion, the component is sound and neither cracks nor pores are observed.

**Dies damage.** Dies do not exhibit excessive damage after the pre-series batch. Only sharp and thin edges around the two circular pins exhibit severe wear (Fig. 6(b)). In any case, this minor problem can be solved with a simple geometry redesign. Apart from some oxide adhesions and flowing scratches in the dies’ surface, they withstand the process’ requirements without any problem.

![Figure 6](image)

**Figure 6-** Small imperfections due to Ceraspray® entrapment (a) and component’s areas where local severe wear of dies is appreciated (b).
Mechanical properties. After the process, the components are subjected to the same heat treatment as HTF parts. The following are the tensile test results of the HTF and SSF components. In all the cases hardness was in the range of 219 – 269 HB.

Table 2 - Tensile tests results of the HTF and SSF manufactured components. Re and Rm are yield and ultimate tensile strengths respectively.

<table>
<thead>
<tr>
<th>Reference test part</th>
<th>Tensile test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Re (MPa)</td>
</tr>
<tr>
<td>Hot Forging average</td>
<td>493.3</td>
</tr>
<tr>
<td>Semisolid Forging average</td>
<td>501.4</td>
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Conclusions

This work demonstrates that it is possible to manufacture complex steel geometry parts in a single step with important material, energy and cost savings compared to classical HTF and maintaining the same mechanical properties. The pre-series batch produced in Mondragon University further demonstrates the robustness and viability of this forming process. The SSF process is now a step closer to the desired industrialisation.

Acknowledgments

The authors would like to sincerely thank CIE Automotive, Sidenor I+D, the Department of Industry, Innovation, Trade and Tourism of the Basque Government and the Ministry of Industry, Tourism and Trade of the Government of Spain for their economical support.

References


