On the Manufacturing of a Gas Turbine Engine Part through Metal Spinning Process

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Abstract. Metal spinning processes represents an interesting alternative to traditional sheet metal forming processes in several industrial contexts, such as automotive and aerospace. In this work, the production of a combustion chamber liner top prototype using AISI 304L stainless steel is proposed, in order to evaluate the process feasibility for the required part geometry. The prototypes production was carried out using a two-stage semiautomatic spinning process. The effects in terms of wall thickness reduction were investigated. Using optical microscopy and Scanning Electron Microscopy (SEM) techniques, the microstructural behavior of the metal subjected to the forming process was investigated, while for an evaluation of the influence on the mechanical properties Vickers micro-indentation tests were performed. The main result of the process, as observed from all the investigation techniques adopted, is the formation of strain induced martensite due to the severe plastic deformation and cold reduction of the material, ranging in this case from 30% to 50%. In some areas of the part section, some rips indicating an excessive tensile stress were also detected.

INTRODUCTION

Although the metal spinning technologies are well known from several centuries, due to the diffusion of other sheet forming technologies such as deep drawing, bending, bulging and so on, the interest in this technology has decreased quite rapidly in the years. However, considering its high flexibility, the possibility to produce axial-symmetric and near net shape objects, sometimes even with high complex geometries, using simple tooling - i.e. an appropriately equipped lathe, whether manual or numerical controlled [1] - spinning process still represents an interesting option where the intended application dictates the production in small dimensions batches or, in other terms, where the costs issue makes not suitable the typical sheet forming process mentioned above. The first applications of spinning technologies, involving manual lathes, regarded the production of domestic objects such as cooking pans and similar, where the dimensional tolerances did not represent a strictly relevant factor but, in the last decades, they gained more attention in several structural application fields, among which the automotive one represents the main example [2]. Thanks to the giant leap forward made with the adoption of high power hydraulic lathes, the extent of the applications also included the aerospace and aeronautic fields where, as an example, spinning processes are employed in the production of rockets nose cones and gas turbine engines parts [3]. Regarding the latter, another interesting application could be the production of combustion chamber liners [4], which are typically made by means of blanking and welding of deep drawn parts. Therefore, this work investigates the feasibility of the conventional metal spinning process for the production of the top part of an annular combustion chamber liner, evaluating the process limits in terms of relationship between the intended part geometry and the material formability, as a potential low cost and time-consuming alternative to the traditional manufacturing methods.

2. EXPERIMENTAL

2.1. Combustion chamber manufacturing

In Figure 1 is reported the CAD model and the dimensions of the considered part. For its production, a two-stage multipass metal spinning process has been adopted that involves appropriately shaped mandrels to obtain the internal and external surfaces, by means of a semiautomatic spinning lathe NOVA SIDERA HERCULES 400. AISI 304 stainless steel, whose composition is fully reported in literature, has been used as the raw material. Experiments have been carried out using sheets with dimensions of 500 mm x 500 mm and 0,6 and 1 mm thickness, considering both the desired final thickness of the part of 0,6 mm and the unavoidable wall thickness variation due the spinning process, subsequently laser cut in order to obtain the required circular geometry. The necessary trial and error approach of this process when dealing with new materials and/or new geometries [5], makes the selection of the right process parameters difficult and it is almost entirely demanded to the operator skills and data availability in literature [6]. The adopted process parameters in this work are summarized in Table 1. During all the experiments, performed at room temperature, an oil emulsion has been used as lubricant.

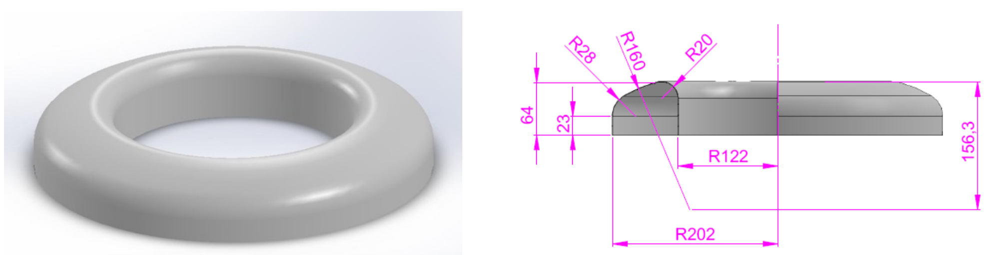


Figure 1. CAD model of the combustion chamber liner top.

TABLE 1. Spinning process parameters.

Experiment N°	**Initial Thickness** *[mm]*	**Tool nose radius** *[mm]*	**Mandrel Speed** *[rpm]*	**Tool feed** *[mm/rev]*
1	0,6	5÷15	400	3
2	0,6	5÷15	400	3
3	1	5÷15	400	3
4	1	5÷15	400	3

As reported in the table, two spinning tools have been used that differs from their nose radius, depending on the particular stage considered in the whole multipass process: In the first spinning passes, the use of the tool having a bigger nose radius allows to induce the stress more gradually in the sheet and it is responsible for the more severe plastic deformation. After that, a more localized and pronounced plastic deformation is imposed by means of the tool with the smaller nose radius, helping the sheet to fit better onto the shaped mandrels.

2.2. Specimens preparation and characterization tests

In order to investigate the effects of the spinning process on the material, in terms of wall thickness reduction, microstructural response and variation of mechanical properties, the most critical areas of the final part have been identified and extracted by means of cutting with a REMET 3000 metallographic cutter, as illustrated in fig. 2 with the enumeration that will be used to expose the results. The obtained sections have been mounted in a conductive epoxy resin in order to be grinded and polished until mirror-like condition ($R_a < 1$ μm). To reveal the true microstructure of the specimens, chemical etching has been performed using Acqua Regia for the base material and the Fry's reagent [7] for the specimens extracted from the spun part. The microstructures of both the base and spun material have been investigated by means of a Zeiss Axioplan 2 Optical Microscope and a Hitachi TM3000 Scanning Electron Microscope (SEM). Furthermore, for a preliminary investigation of the process influence on the mechanical properties of the material, Vickers microhardness tests have been performed on all the specimens, with an indentation load of 200 g applied for 20 s, in order to compare the effects of the cold working on the several areas considered.

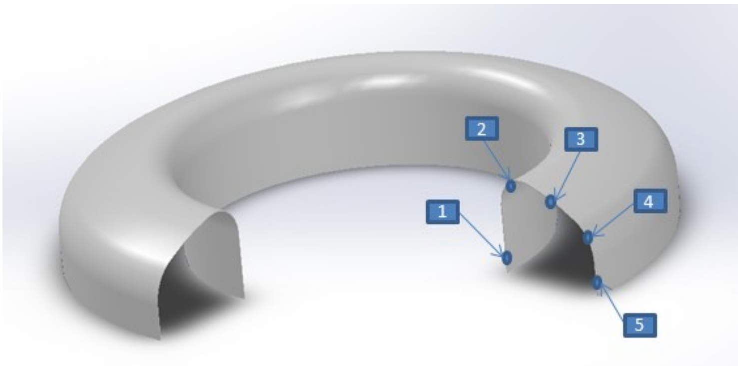
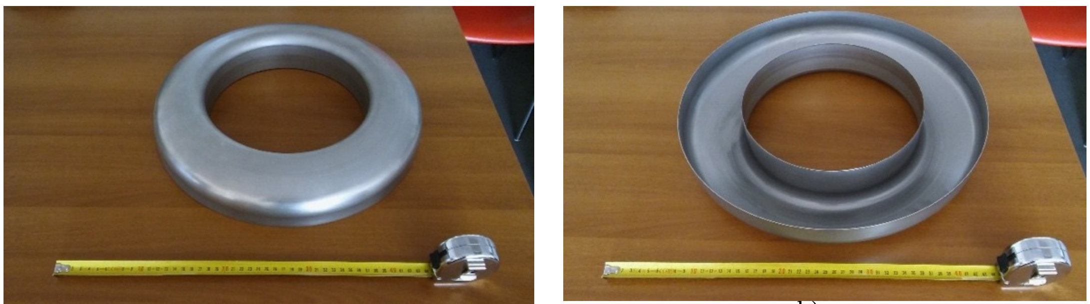


Figure 2. Section areas of the spun part considered for the investigations.

3. RESULTS AND DISCUSSION

Figure 3 illustrates the obtained part from the sheets having the initial thickness of 1 mm. The experiments conducted with the 0,6 mm thick sheets failed during the process due to an excessive thickness reduction in the areas where the curvature is high (i.e., areas 2 and 4). The wall thicknesses measured on the considered areas of the spun part are reported in Table 2. Results shows a considerable thickness reduction, especially in the areas 1 and 2, where the usage of the tool having the bigger nose radius is more pronounced due to the first stages of the part spinning. However, the thickness reduction on the other areas is still remarkable.



a) b)

Figure 3. Front view (a) and rear view (b) of the prototype.

Table 2. Wall thickness reduction in the several areas of the spun part.

Specimen	Thickness [mm]
1	0.497
2	0.520
3	0.670
4	0.720
5	0.720

The results relative to the Vickers microhardness tests are synthetically illustrated in the diagram reported in fig.4. As can be noted, quite higher values of hardness have been observed in the spun part, in comparison with the base material, especially in the areas 1,2. This last result is also in perfect agreement with the local wall thickness variations mentioned above. This steep hardness increase is also justified by the severe microstructural changes that took place in the spun material, as can be seen in the optical images reported in fig.5 which illustrates, as an example, the comparison between the microstructures of the base material and the one observed in the specimen 5: The former is fully austenitic with equiaxed grains, in which twin defects are also clearly visible. Besides the grains elongation due to the plastic deformation, in the spun material the presence of strain-induced martensite has also been highlighted: this transformation, as reported in literature from the studies conducted on austenitic stainless steels [8], is influenced by the following aspects:

- The steel composition, especially regarding the carbon and the austenite stabilizers contents;
- The temperature at which the plastic deformation process takes place, that strongly influences the strain induced martensite percentage;
- Depending on the two previous points, the entity of S*tacking Fault* defects, associated with a specific value of the *Stacking Fault Energy* [9], which represents the driving force for the strain-induced martensite formation process.

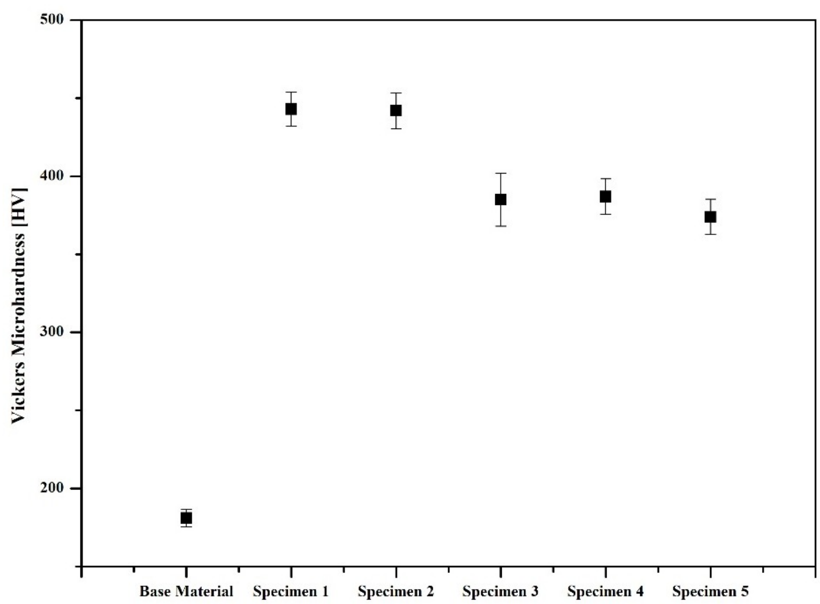
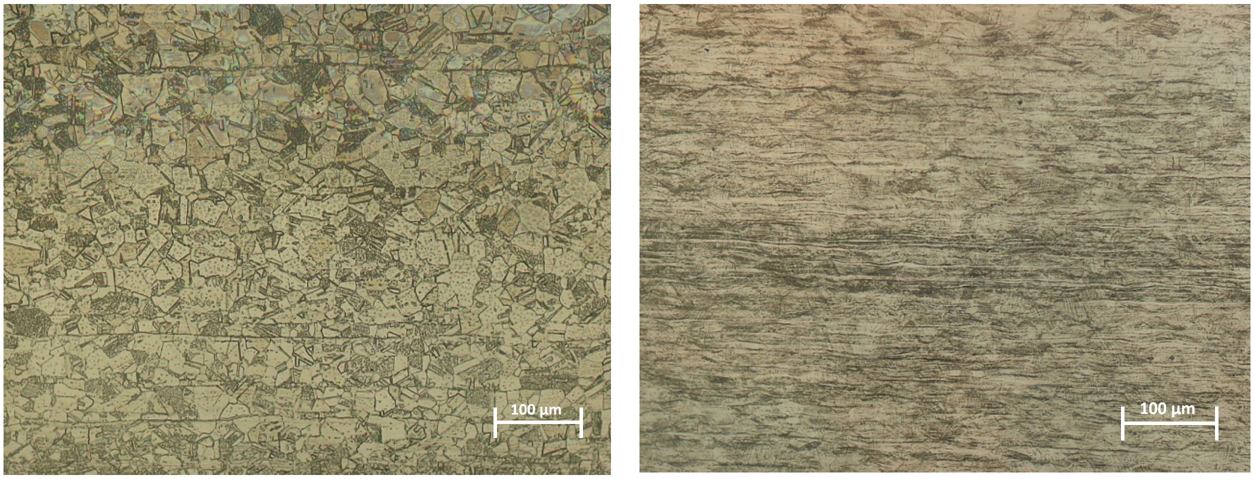


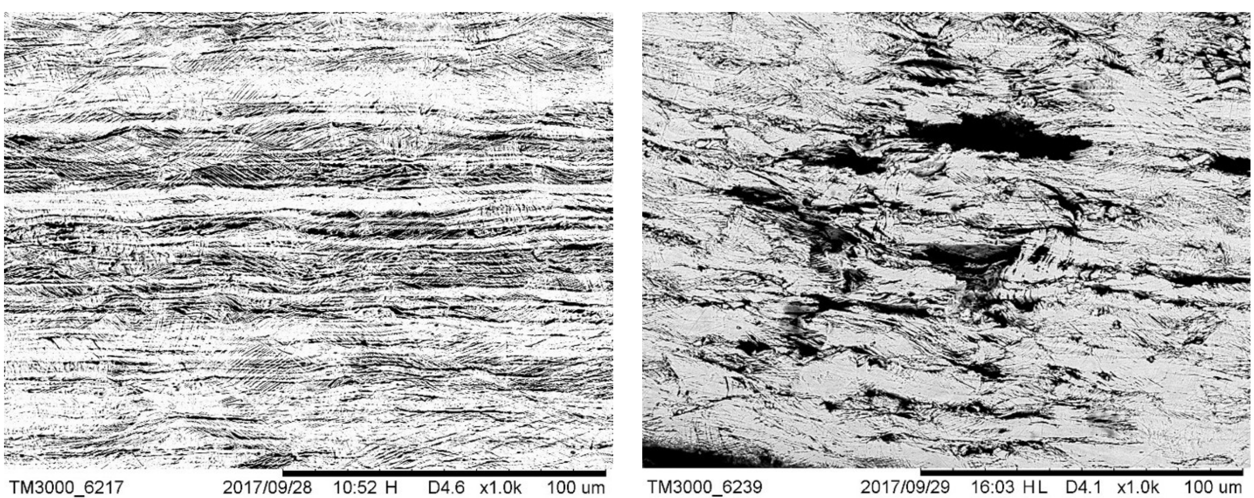
Figure 4. Comparison between the Vickers microhardness values of the base material and the spun part.



a) b)

Figure 5. Optical macrographs of the base material (a) and the specimen 5 from the spun part (b) (magnification: 200X).

For the spun part, the investigations performed with SEM offers more details about the effects of the spinning process on the material. As an example, in fig.6 are reported the images took from the specimens 3 and 5. Besides the clearer visibility of the near-whole martensitic microstructure, results show the presence of several defects through the thickness of the spun material: in the specimen 5 the defects, in the form of rips (the darker areas in the image), are clearly distinguishable and highly distributed through the material, whereas in the specimen 3 they seem to coalesce in specifical areas. However, this kind of defects have been noticed in all the specimens investigated, suggesting the need to find the right set of process parameters that prevents the formation of cracks into the final part (i.e., an appropriate ratio between the feed and the mandrel speed and the use of the correct spinning tool, as well as the correct lubricant). More specifically, this kind of defects are due to the excessive tensile stresses induced in the sheet, caused by an incorrect choice of the feed value.



a) b)

Figure 6. SEM images of the specimen 5 showing the presence of dislocated defects (a) and the specimen 3 showing defects coalescence (b) (magnification: 1000X).

CONCLUSIONS

Based on the experimental results observed, the final considerations about the employment of the metal spinning process for the production of aeronautic engines combustion chamber parts can be synthesized as follows:

- The proposed process determines an undesired thickness variation, being different in several areas of spun part and not respecting the intended uniform value of 0,6 mm: although the values obtained suggests an optimization of the whole process, this result is unavoidable when employing manual or semiautomatic spinning processes;

- Although the process is fully capable to reproduce the geometry intended for the final part, the assessment of the correct set of the process parameters represents a great limitation due to the necessary trial and error approach, as highlighted from the defects formation observed in the experimental results;

- The final part is characterized by an intensive increase in hardness, as clearly observed by the Vickers microhardness tests: this result is fully consistent with the strong cold working of the sheet in combination with the formation and evolution of strain-induced martensite in all the areas of the final part investigated, as can be observed from the optical and SEM images of the spun part. This result also suggests the necessity to perform a thermal treatment that induces a full recrystallization apart from the stress relieving.

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