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Study on the Spinning Forming Process of a Bowl-Shaped Part with Hastelloy X Raw Material

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Abstract

One of the basic needs in the defense industry is the manufacturing of thin-slice and high-plasticity pieces, but thin-slice pieces with complex geometric shapes can often not be manufactured by conventional ways or cost more than conventional ones. Usually, the method of manufacturing these pieces is to use the spinning. In addition to quality and precision in size, these pieces must be of high strength, which makes them difficult to manufacture. In this study, spinning with thermal methods in High Temperature Furnace was used to form a bowl. The Hastelloy x alloy was used for fabrication. All tensile, hardness and microstructure tests were performed on the formed part by optical microscopy after forming and heating processes. After completing the process of manufacturing, the quality of its dimensions were also measured by a 3D optical scanner. The Hastelloy x alloy loses its plasticity after 45% cold-working, which significantly reduces elongation and increases hardness. The furnace at 1177°C was used to increase the workability. The use of the furnace results in full recrystallization of the microstructure, reducing the hardness by 62 percent, increasing by 6 times the elongation, and by 40 percent the yield stress, which provides the conditions for further cold work. Experimental examination of surface quality using optical scanners shows that the average thickness distribution obtained for this experiment is 0.13. This value represents only a difference of less than 15% with the value obtained by software 0.15, indicating that the dimension produced is in good agreement with the sample.

Keywords: Spinning • Hastelloy x • Spinning Forming • Heat treatment Hastelloy x

Introduction

The need to manufacture the low-cost complex pieces in the aerospace, military and oil and gas industries has led researchers to develop new methods in manufacturing. The most commonly used industrial components are conical-cylindrical components with fixed or variable thickness profiles of titanium, Inconel and superalloys and stainless steels with dimensional and geometric tolerances. One of the most practical methods for manufacturing shell pieces is the use of a spinning, which is a flexible method with specific functional accuracy. The most important feature of the spinning technique that makes this method efficient is the production of symmetric metal thin-slice pieces, is that the force is applied locally and at a low intensity. In addition, the accuracy and quality of the surface after forming are acceptable in this method. For this reason, the spinning method is one of the suitable methods for forming a low thickness sheet to produce hollow axial symmetric thin wall parts. Also, the use of the spinning process in the manufacture of various types of superalloys, due to their high strength to weight ratio, the type of forming process and numerous effective parameters, and the widespread use in the military industry, as well as the scarcity of the number made of this type have been emphasized in various studies investigated the mechanical properties of Inconel 708 alloy after spinning and heating. The results showed that heating had a direct effect on yield stress and elongation percentage [1].

In another study, investigated the hardness and microstructure of components made of 718 alloy. Based on their studies, it was found that heating after forming reduced the hardness of the part by nearly 100%. This is because the low heating temperature causes the transition to the delta phase in the workpiece, which increases the workpiece stiffness. Hihu experimentally formed Haynes 282, alloy 718, alloy 600, SS 316L sheets by a spinning. In this paper, the effect of feed rate was investigated. In addition, we used heating to reduce the hardness of the Haynes and 718 alloys. The results showed that this reduction resulted in the reduction of hardness and improvement of microstructure and hardness of the workpiece and reduction of residual stresses. This paper investigates the spinning of the Hatselloy X alloy to produce a bowl-shaped piece under high thermal

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stresses [2]. It should be noted that the Hastelloy X alloy loses its plasticity due to its high hardness after cold working. This condition must be attempted to be restored by heating again. In addition, the effect of heating and the effect of cooling on the microstructures, hardness of the pieces and their mechanical properties are also investigated.

Methodology

The three-dimensional drawing of the workpiece is shown in Figure 1. To perform the test, the sheets were first cut to a diameter of 330 mm and a thickness of 1.25 mm. The alloy used in chemical analysis is Hastelloy x, which is listed in Table 1.

Si	C	Mn	S	P	Cr	Ni
0.34	0.1	0.59	≤ 0.03	0.02	20.54	Balance
W	Cu	Co	Al	Ti	Fe	Mo
0.61	0.18	1.14	0.22	0.01	17.84	8.83

Table 1: Chemical composition of AMS 5536 alloy.

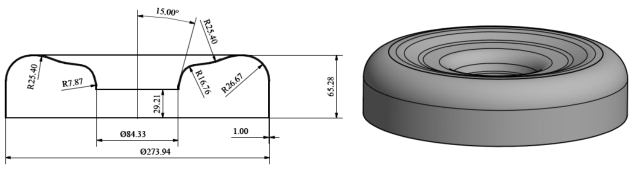

Figure 1: Three-dimensional drawing of the workpiece.

The mandrel is one of the most important parts of the spinning process. In this study, two mandrels were fabricated by CNC turning machine by alloy steel. Mandrels have been attempted to be made very carefully from 3D drawings of workpiece. One of the mandrels was used to form the inner part of the workpiece and the other was used to form the outer part. Experimental experiments were performed by spinning machine with a diameter of 120 mm and a radius of 5 mm. Because the material of the AMS 5536 has work hardening property, after a certain time of the forming process, the alloying ability of this alloy is reduced, so the furnace should be used to improve the microstructure [3]. All specimens are removed from the spinning machine after a certain amount of cold working and reducing their workability. Then, one of these specimens is examined by optical microscope. Other samples are pre-heated to a temperature of 1177°C for 5 minutes. After applying heating and cooling procedures upon the samples in to cool to ambient temperature. The microstructure of the specimens was examined by optical microscopy after heat treatment to investigate the effect of heat treatment. After the heating procedure, we cool the specimens with water to bring their temperature to room temperature. The microstructure of the specimens was examined by optical microscopy after heating to investigate the effect of heating procedure. The specimens prepared for microstructure examination were polished by sandpaper and abrasives and then etched with Kalling No.2 solution with chemical composition according to Table 2.

Kalling No. 2	Ethanol	Hydrochloric acid	$CuCl_2$
	100 ml	100 ml	5 g

Table 2: Chemical composition of Kalling No.2 etch solution.

We also performed sample tensile testing and hardness testing of the components after the first forming step and after the heat treatment process. Table 3 shows the sample dimensions for the tensile and hardness test.

Sample	G (mm)	W*t (mm)
	25	6*1.22

Table 3: Dimensions of tensile and hardness test samples.

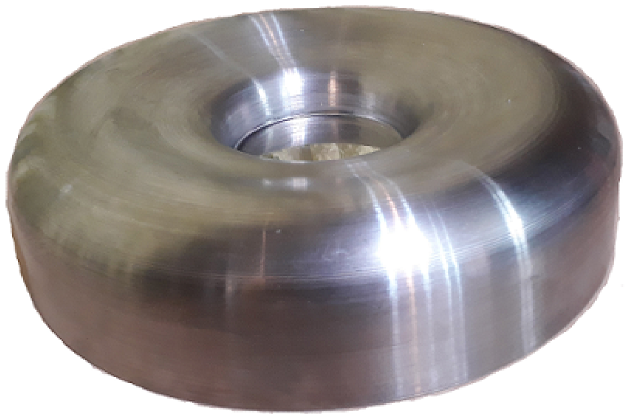

Figure 2: Image of the formed piece.

The formed piece was scanned by a 3D optical scanner for dimensional examination. Then, the point cloud and the three-dimensional drawing of the workpiece were drawn. For more precise comparison, we compared the 3D drawing of the production piece with the designed workpiece by which the Mandrels were made by Catia software. In addition, we cut the manufactured piece by WIRECUT to measure the quality of its thickness along its plane symmetry by micrometer.

Results and Discussion

Using optical microscope images, we examined the microstructures and grain-size distribution of the pieces. In Figure 3 you can see an optical microscope image of the AMS 5536 alloy plate before heating [4].

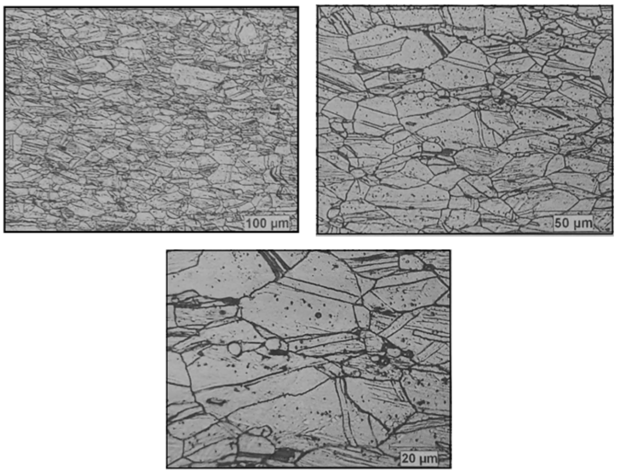

Figure 3: Microstructure of hastelloy x after forming.

As previously described, the AMS 5536 alloy has the work hardening effect and, as a result of cold working, its hardness increases and its elongation decreases. This alloy is so hard-working that it can be torn to pieces by applying more force. After 45% cold work, the sheet is not capable of withstanding deformation and will yield and break as shown in Figure 4.

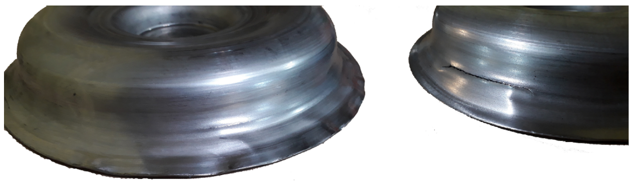

Figure 4: Tearing sheet after cooling process.

The microstructure of the specimens after the first stage of formation is composed of austenitic background and carbides phase. Slip lines are high density. At this stage, we performed the tensile and hardness test of the specimens. The stress-strain diagram of samples obtained from the workpiece with a certain percentage of cold work, tested at ambient temperature, is shown in Figure 5. The yield and final stresses are in accordance with AMS 5536, but the percentage of specimen elongation is negligible (9%). This value differs sharply from the results obtained in the usual case (45%) (K Zaba1 2014 and AMS5536, 1960), which can be attributed to the cold-wrok performed on this sheet. The results of this tensile test are consistent with the practical results that lead to sheet tearing (Figure 4), since the continuation of the forming process results in the shear and tearing of the sheet [5].

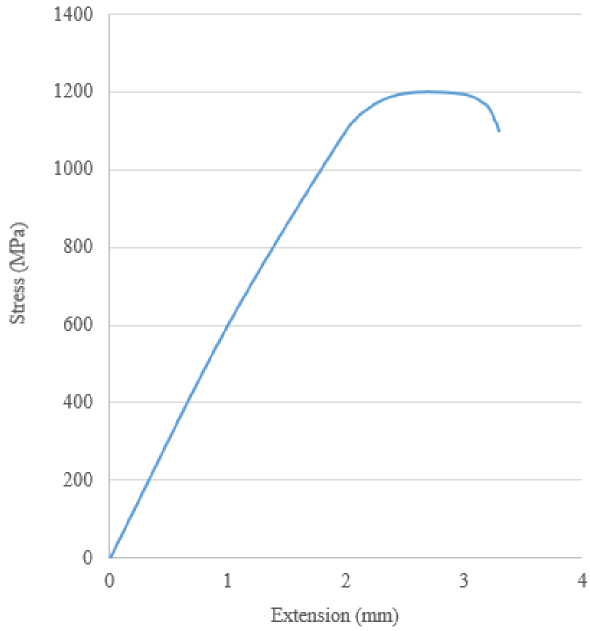

Figure 5: Stress-strain curve of sample after coldworking.

Comparing these results with the hardness values recorded for the raw materials (12 HRCs), we can see that there was a three-fold increase in hardness and a 6-fold decrease in the percentage of elongation. This is why the workpiece loses its flexibility and tears as shown in Figure 4. At this point, the alloy has completely lost its plasticity and has been subdued and torn by the use of low force. The samples were annealed by heat treatment to restore the flexibility to the workpiece and continue the forming process. The heating steps are described in the previous section. After the heating step, the microstructure of the components was examined.

Examination of grain size before and after heat treatment shows that now the grains are finer. The reason for this is that the grains have had opportunity to be reproduced and full recrystallization. The strain-stress diagram of the specimens after heating (Figure 6) indicates that the elongation rate (in percents) was increased, yield stress was decreased, and final stress was decreased, significantly. By comparing the results with the AMS 5536 standard, it can be seen that the results of the tensile test are very small compared to the results of the raw and non-cold work samples. In other words, heat treatment has restored the mechanical properties of the AMS 5536 sheet to its original state. Due to this unique feature, increasing heating times can be used to restore the mechanical properties to the original state and to create more complex and high elongation components using the spinning method.

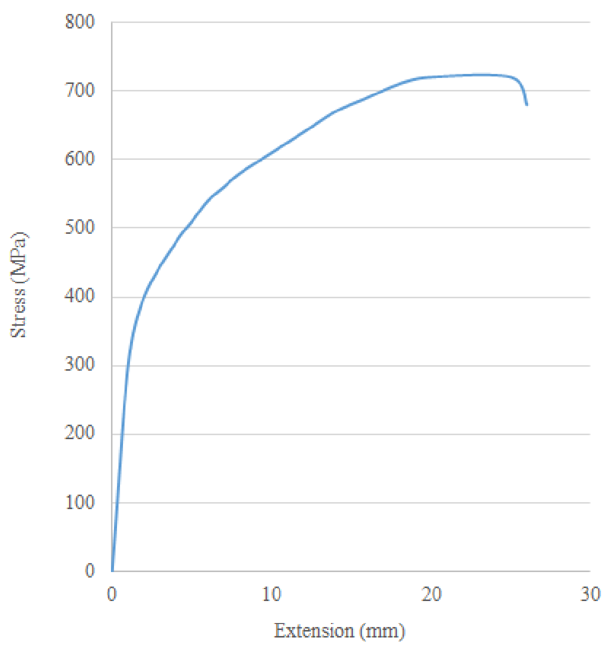

Figure 6: Stress-strain curve of the sample after heat treatment.

The hardness results after the heat treatment process indicate that the hardness after the heat treatment process has been reduced to 14 HRC. Therefore, it is expected that this 62% reduction compared to pre-heating will improve the formability of the pieces. In addition to the microstructural properties, dimensions and size of the workpiece are among the most important parameters affecting the quality of the workpiece surface. The point cloud results obtained from 3D optical scanners by catia software and point-by-point comparison with the drawing are shown numerically and schematically in Figure 7. As can be seen in Figure 7, the maximum deviation is 0.9 mm and in most parts of the piece, the deviation is about 0.2 mm. For a closer look, all of the Excel outputs were extracted from the catia software. The mean deviation of the points on the x, y, and z axes was calculated. Table 4 shows the mean deviation of the two models in three coordinate directions.

Mean standard deviation	X	Y	Z
	0.2	0.21	0.15

Table 4: The standard deviation of the mean of the model distribution and the model in three coordinate directions.

The highest deviation was obtained from the mean along the y and x axis and equal to 0.21mm. This deviation is probably due to the spring-back characteristic that may have formed along these two axes after deformation and completion of the forming process. For a closer look, the piece was cut by a wirecut machine at different distances from the outer diameter to measure the cross section thickness. Also the outputs of the excel points on the cut profile from the plane symmetry of the workpiece were extracted from the catia software values obtained from the catia software and the experimental values are the values obtained from the cut production piece, whose thickness in profile is measured in micrometers. The results of the cut are in excellent agreement with the results obtained from the software and this is a confirmation of the quality of the work piece and the quality of the piece being manufactured. However, there are differences in the thickness of the workpiece at different distances relative to the axis of symmetry. The reason for the differences in thickness with respect to the main sheet can be attributed to the nature of the workpiece. The workpiece has work hardening property under the work force applied, and this work hardening property decreases with increasing length and workpiece stiffness, the molding force has increased in some parts of the workpiece. It has also caused deformation and reduced thickness of the profiles.

Conclusion

In this work, the spinning forming of the AMS 5536 alloy was carried out along with the use of heating to improve the microstructure and mechanical properties. Improved microstructure and mechanical properties allow heat treatment to restore mechanical properties to the desired state as often as possible. This feature makes it possible to form complex pieces with a variety of rotational forming methods. The results of comparing the scanner fragment thickness distribution showed the average thickness difference of all workpiece points from the x axis 0.2 mm, the y axis 0.21 mm and the z axis 0.15 mm indicating good conformity of the manufactured piece with the sample piece. Experimental results of the produced piece thickness distribution show a standard deviation of 0.13 mm thickness distribution, which indicates uniformity of thickness distribution across all parts of the workpiece, and is in excellent agreement with the software standard deviation of 0.15 mm.

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