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Application of HIP-NNS to Large Complex Products Using Super Duplex Stainless Steel Powder

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Abstract. In recent years, the productivity of offshore plants has been improved and the field of production from shallow water to deep sea has been expanded. Along with this, it is required that the plant equipment be upsized and maintenance-free. The conventional manufacturing method for duplex stainless steel parts such as valves for plant equipment was mainly forging. There is a problem though, it is difficult to obtain homogeneity with the physical characteristics. One solution to this problem is powder sintering using HIPed near net-shaped (HIP-NNS) products. However, near-net manufacturing requires advanced capsule design and powder filling control. In this paper, we will report the results of the HIP-NNS method when manufacturing a large-sized complex-shaped powder sintered product using the world's largest HIP device.

Introduction

In recent years, the oil and gas industry has been developing offshore oil fields, with the development moving from shallow to deep water. One of the by-products of deep-sea oil exploitation is corrosive materials such as hydrogen sulfide (H_2S) and carbon dioxide gas (CO_2). These highly corrosive by-products require components and equipment that can withstand both high pressure and corrosive fluids for a long period of time. Therefore, duplex stainless steel and super duplex stainless steel are often used. The hostile environment of deep-sea oil extraction also requires maintenance-free parts. In addition, there is a need to increase the size of parts produced in order to facilitate increased production. Conventionally, the manufacturing method for valves, etc. has been mainly done through forging. However, since it is difficult to obtain uniformity of mechanical properties such as strength and corrosion resistance at the weld at the time of assembly, a weld-less integrated shaping technique is required. Therefore, as a method to replace forging, near-net shaping by HIP is used. By utilizing this method, it can be expected that material weight and machining time will be reduced. [1] In this study, in order to manufacture large parts using MTC'S Giga-HIP, a large flange and valve body were manufactured using UNS S32505 powder, which is super duplex stainless steel. The resulting shape was then compared with the designed shape and the mechanical properties due to differences in heat treatment conditions were also investigated.

Dimension evaluation - Flange

Method

Fig. 1 shows the target shape after HIP. Based on this target shape, the capsule was designed assuming a powder filling rate determined using a pretest. In order to allow the capsule to shrink evenly, mild steel with a plate thickness of 3.2 mm was used for all sections. [2] The powder used was UNS S32505, which is a super duplex stainless steel. The powder filling was facilitated with vibration. The actual filling rate of the powder was 7% higher than the assumed rate. The HIP treatment temperature was 1150 °C [3] and the pressure was 118 MPa. Dimensional measurements were performed before and after HIP with the target shape and the actual shape compared after HIP.

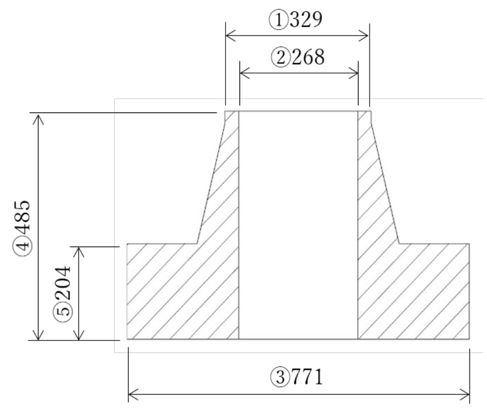

Figure 1. Target shape of Flange

Results

The dimensional measurement results are shown in Table 1. Dimensions were measured at the locations described in the dimensions shown in Fig. 1. When comparing the target dimensions with the actual dimensions after HIP, the maximum difference was 4.7%. In order to eliminate errors due to the difference in filling rates, the expected dimensions after HIP and the actual dimensions after HIP when the capsules were filled with were compared. The difference was 1.2%. Figs. 2 and 3 show the measurement results with a 3D digital analyzer. Fig. 2 compares the design shape of the capsule before HIP and the actual shape. The maximum difference between the design dimensions and the measured dimensions was 3.3 mm. Fig. 3 compares the expected shape after HIP and the actual shape after HIP calculated using the actual filling rate. The maximum error was 5.6 mm. The difference in maximum error between Figs. 2 and 3 was 2.3 mm.

Table 1. Dimension measurements results of Flange

	①	②	③	④	⑤
After HIP [mm]: A	343	280	801	508	212
Goal shape [mm]: G	329	268	771	485	204
Error [%]: E	4.3	4.5	3.9	4.7	3.9
After HIP shape AFR [mm]: A_{AFR}	341	278	798	502	211
Error AFR [%]: E_{AFR}	0.6	0.7	0.4	1.2	0.5

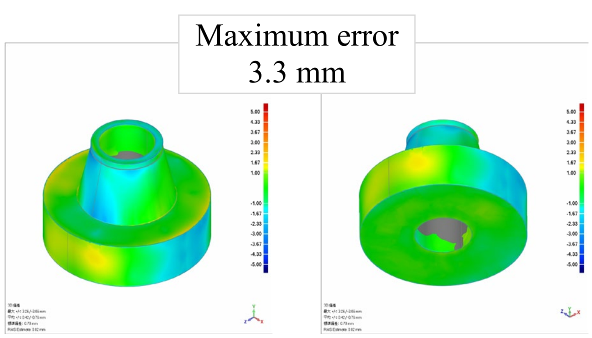

Fig. 2 Compares the design shape of the capsule before HIP and the actual shape

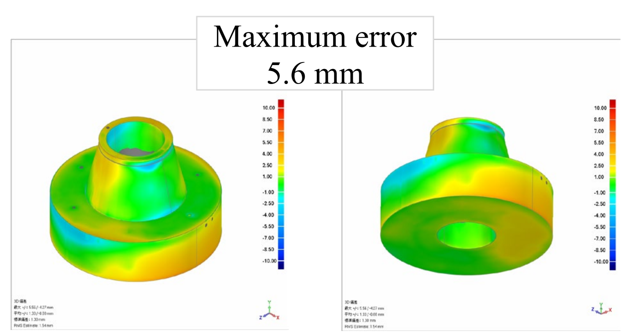

Fig. 3 Compares the expected shape after HIP and the actual shape after HIP calculated using the actual filling rate

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Dimension evaluation - Valve body

Method

The target shape of the valve body is shown in Fig 4. Based on this target shape, the capsule was designed assuming a powder filling rate the same as the actual rate for the flange. The capsule was made of mild steel with a plate thickness of 3.2 mm. The powder used UNS S32505, which is a super duplex stainless steel, and the powder was filled using a vibrator. The filling rate was 3.0% lower than the designed value. As with the flange, the HIP treatment temperature was 1150 °C and the pressure was 118 MPa. Dimensional measurements were performed before and after HIP, and the target shape and the actual shape after HIP were compared.

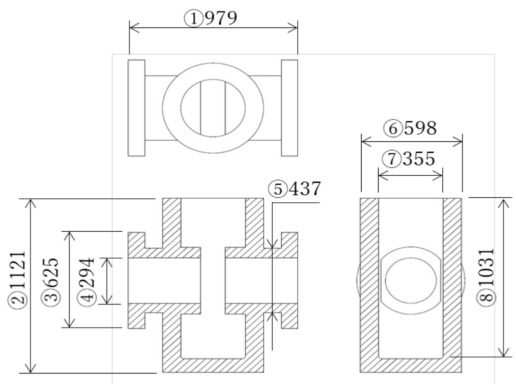

Figure 4. The target shape of Valve body

Results

The dimensional measurement results are shown in Table 2. Dimensions were measured at the locations described in the dimensions shown in Fig. 4. When comparing the target dimensions with the actual dimensions after HIP, the difference was up to 5.7%. In order to eliminate errors due to the difference in filling rates, the expected dimensions after HIP calculated by the actual filling rate and the actual dimensions after HIP were compared. The difference was 2.3%. Figs. 5 and 6 show the measurement results with a 3D digital analyzer. Fig. 5 compares the design shape of the capsule before HIP with the actual shape. The maximum difference between the design dimensions and the measured dimensions was 13.2 mm. Fig. 6 compares the expected shape after HIP and the actual shape after HIP calculated using the actual filling rate. The maximum error was 15.7 mm. The difference in maximum error between Figs. 5 and 6 was 2.5 mm.

Table 2. Dimension measurements results of Valve body

	①	②	③	④	⑤	⑥	⑦	⑧
After HIP [mm]: A	949	1110	610	294	412	571	360	1030
Goal shape [mm]: G	979	1121	625	294	437	598	355	1031
Error [%]: E	-3.1	-1.0	-2.4	0	-5.7	-4.5	1.4	-0.1
After HIP shape AFR [mm]: AAFR	943	1105	604	291	406	574	352	1013
Error AFR [%]: E_{AFR}	0.6	0.5	1.0	1.0	1.5	-0.5	2.3	1.7

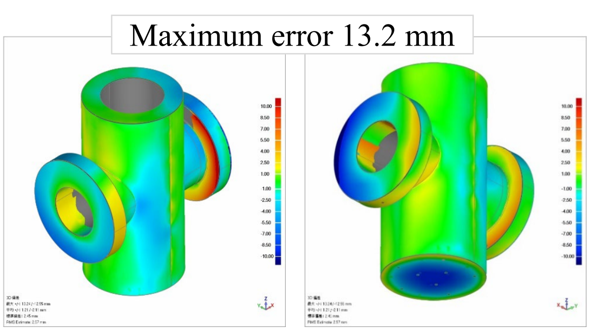

Fig. 5 Compares the design shape of the capsule before HIP with the actual shape

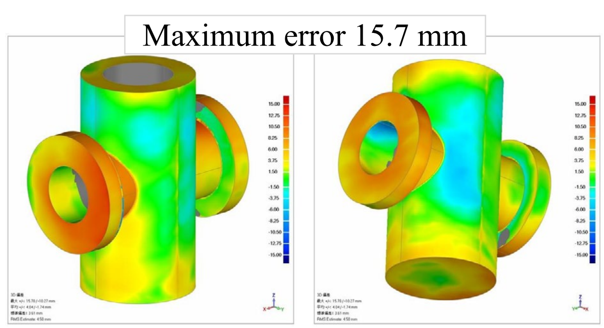

Fig. 6 Compares the expected shape after HIP and the actual shape after HIP calculated using the actual filling rate

Discussions

The reason why the target dimensions of the flange and the actual dimensions after HIP were off by 4.7% is thought to be that the capsule shrank less than expected because the powder was filled 7% more than the expected filling rate. The reason why the target dimensions of the valve body and the actual dimensions after HIP were off by 5.7% is thought to be that the powder was filled 3% less than the assumed filling rate, and the shrinkage of the capsule was larger. In addition, the difference between the dimensions predicted from the actual filling rate after HIP and the actual dimensions after HIP is up to 1.2% for the flange and 2.3% for the valve bodies. It is necessary to accurately predict the filling rate at the time of design and manage the actual filling rate according to the design value.

The maximum error difference between both the flange and valve body in the pre-HIP capsule design shape and the actual capsule shape, and the maximum error difference between the post-HIP shape and the respective powder filling rate is approximately 2.5 mm. This is considered to be a small difference due to the size of the product, suggesting that the capsule accuracy before HIP also affects the shape after HIP.

In addition, the valve body had a larger difference between the capsule before HIP and the design shape and the actual shape than the flange. This is thought to be because the number of parts increased and the number of welding points increased due to the complexity of the shape, and the capsule was distorted by the heat of welding. Therefore, it is necessary to restrain the capsule during welding and to correct distortion after welding.

Mechanical Properties of Flange

Method

The flange, after dimension evaluation, was subjected to 2.5 hours of heat treatment at 1050 °C and a tensile test, a Charpy impact test, corrosion test, and micro-structure observation were performed. For the corrosion test, a pitting test using ferric chloride was performed. As to the micro-structure observation, the amount of ferrite and intermetallic compounds and nitrides present were confirmed. Sampling was based on NORSOK standard m-650.

Results

Table 3 shows the results of the tensile test and the Charpy impact test. All test results met the NORSOK standard. Table 4 shows the corrosion test results and micro-structure observation results. Fig. 7 shows a photograph of the microstructure. The amount of corrosive thinning was a maximum of 0.2 g/m^2. The amount of ferrite was 40.9 - 46.3%. Also, it was confirmed the intermetallic compound and nitride were very small amounts.

Table 3. Tensile test and Impact test results

	TENSILE TEST			IMPACT TEST (-46 °C)	
	0.2% proof Stress [MPa]	Ultimate tensile strength [MPa]	Elongation [%]	Absorbed energy [J]	
				Average	Minimum
NORSOK Standard	≧550	≧750	≧25	≧45	≧35
Flange	615-624	872-876	37	68-171	66-168

Table 4. Corrosion test and Micrographic examination test results

	CORROSION TEST ASTM G48	MICROGRAPHIC EXAMINATION	
	Weight loss [g/m^2]	Ferrite content [%]	Intermetallic phases and nitride precipitates
NORSOK Standard	<4.0	40 - 60	-
Flange	0.1 - 0.2	40.9 - 46.3	Trace

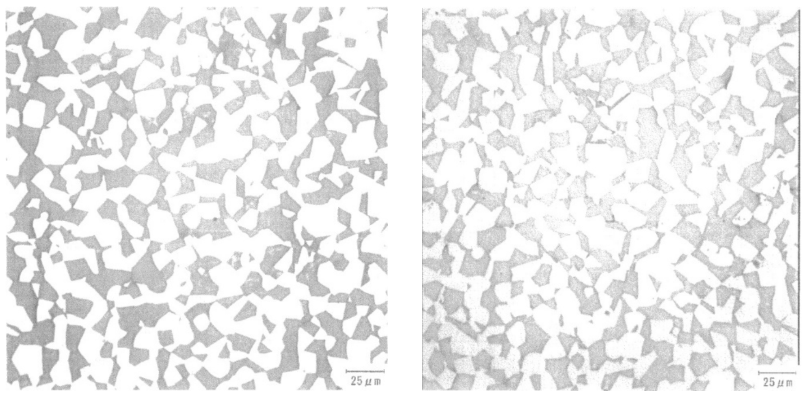

Figure 7. Micrographic of Flange (Left: inner position, Right: surface position)

Mechanical properties of Valve body

Method

After dimension evaluation, the valve body was heat-treated at 1100 °C for 4 hours, and tensile tests, Charpy impact tests, corrosion tests, and micro-structure observations were performed in the same manner as the flanges. Sampling was based on NORSOK standard m-650 with measurements taken at various locations.

Results

Table 5 shows the tensile test and the Charpy impact test results. All parts met the NORSOK standard. Table 6 shows corrosion tests and micro-structure observations. NORSOK standards were met in all respects. Fig. 8 shows microstructure observation photographs of the surface position and inner position. There was no significant difference between the surface and inner portions of the valve body.

Table 5. Tensile test and Impact test results

	TENSILE TEST			IMPACT TEST (-46 ℃)	
	0.2% proof Stress [MPa]	Ultimate tensile strength [MPa]	Elongation [%]	Absorbed energy [J]	
				Average	Minimum
NORSOK Standard	≧550	≧750	≧25	≧45	≧35
Valve body	600-633	855-876	37.4-38.4	104-181	96-173

Table 6. Corrosion test and Micrographic examination test results

	CORROSION TEST ASTM G48	MICROGRAPHIC EXAMINATION	
	Weight loss [g/m^2]	Ferrite content [%]	Intermetallic phases and nitride precipitates
NORSOK Standard	< 4.0	40 - 60	-
Valve body	0.3 - 0.4	42.9 - 44.7	OK

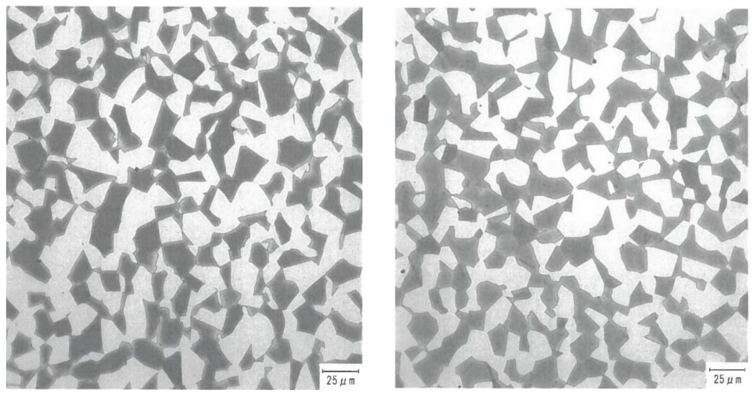

Figure 8. Micrographic of valve body (Left: Inner position, Right: Surface position)

Discussions

Both the flange and the valve body were able to meet the mechanical properties required by NORSOK. As for the heat treatment temperature, in both cases of 1050 °C and 1100 °C, the mechanical characteristics of NORSOK were satisfied. For these reasons, it is considered that even large products such as those using MTC'S Giga-HIP can obtain NORSOK certification.

Conclusions

In the dimensional evaluation, in order to manufacture with NNS, it was found that the powder can be filled according to the filling rate of the design value and the shape management of the capsule can be brought closer to the target shape by filling the powder according to the filling rate of the design value and increasing the production accuracy of the capsule. This indicates that the powder filling rate and the shape management of the capsule are critical.

Since the large flange and valve body were able to meet the mechanical properties of NORSOK, it is thought that even large products such as those using MTC'S Giga-HIP can obtain NORSOK certification.

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