A Development of PM HIP NNS Manufacturing Process for Subsea Valve Bodies Made of Duplex Stainless Steel

Hiroshi URAKAWA*, Toyohito SHIOKAWA**

*Shimoda Iron Works Co., Ltd.
**Metal Technology Co. Ltd.

Abstract

Shimoda Iron Works Co., Ltd. has been developing a new process to manufacture piping components using PM HIP NNS process in collaboration with Metal Technology Co. Ltd.. A trial production of valve bodies for subsea oil plants was made by the HIP process using duplex stainless steel powder. According to the investigation results of the product, their properties satisfy all requirements of NORSOK standard.

1 Introduction

Shimoda Iron Works Co., Ltd. (hereinafter "Shimoda") has been developing a new process to manufacture piping components by the PM HIP NNS (Powder Metallurgy - Hot Isostatic Pressing - Near Net Shape) process in collaboration with Metal Technology Co. Ltd. (hereinafter "MTC") who specializes in HIP treatment. Shimoda Technical Report No.E-3[1)] has already reported the investigation results of valve bodies for power plants made of grade 91 steel manufactured by the PM HIP NNS process. This paper reports the another application of the HIP process to valve bodies made of duplex stainless steel for subsea oil and gas plants.

Recently, when drilling offshore oil and gas wells, piping components are required to withstand deep sea pressure and highly corrosive environment because of the depletion of resources in the shallow sea area. For these applications, duplex stainless steel is promising due to its high strength and corrosion resistance.

Generally, complex shaped products such as valve bodies are manufactured by casting. Forging is desirable in order to obtain higher strength and reliability, however it is often not applicable because not only the yield is significantly reduced but also some surfaces of the product cannot be finished by machining. On the other hand, the HIP process makes it possible to obtain the strength and toughness comparable to those of forged products as well as the near net shape close to the cast products.

Therefore, a trial production of subsea valve bodies using duplex stainless steel powder was performed by HIP NNS (Near Net Shape) process and their characteristics were investigated. This development was carried out with the assistance of the "Strategic Basic Technology Advancement Support Project" of the Ministry of Economy, Trade and Industry (adopted in 2017) of the Japanese Government..

2 Powder

2.1 Material

The duplex stainless steel selected for this development is 25Cr-based super duplex stainless steel which has excellent corrosion resistance. Its UNS number is S32505. It is specified in ASTM A988[2) which is a standard for HIP products.
The powder for this trial production was imported. The specified range of the chemical composition and the actual values of ladle analysis are shown in **Table 1.**

Table 1 Chemical composition (%)

		C	Si	Mn	Ni	Cr	Mo	N	Cu
ASTM A988 S32505	min.	-	-	-	4.5	24.0	2.9	0.25	1.50
	max.	0.030	1.00	1.50	7.0	27.0	3.9	0.30	2.50
Ladle		0.017	0.52	0.63	6.45	25.8	3.07	0.28	1.67

2.2 Properties of the powder

As shown in **Figure 1**, the powder particle sizes are approximately 70-300 μm and tiny particles (called "satellites") adhere to the surface. **Figure 2** a) and b) show the microstructure of the cross section of the powder. The structure is duplex structure with a grain size of approximately 20 μm.

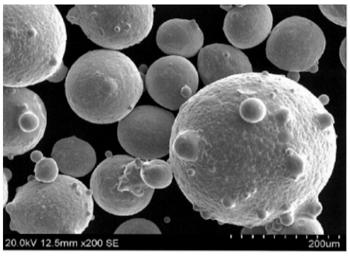
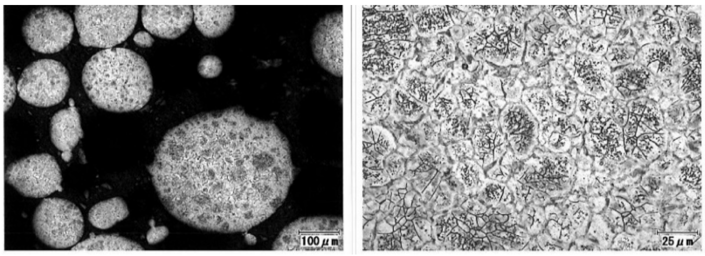


Figure 1 Powder particle



a) Structure of the section b) Magnified

Figure 2 Microstructure of the powder

3 Configuration of the product

The valve body selected for the trial production is a body for conduit type gate valve. The feature of this type is that the flow path loss can be minimized because of the constant flow path cross-section. On the other hand, when stopping the flow, the gate is lowered to the bottom therefore a space for the lowered gate is required at the bottom. (Refer to the general construction of the conduit type gate valve shown in **Figure 3**.)
The specification of the valve body is 900 lbs.-12", and its drawing is shown in **Figure 4**. The size of the finished product is 1,121 mm height × 979 mm width × Φ598 mm body diameter.
Two valve bodies were manufactured. One was finished to the final product and the other was a sample for the investigation of the properties.

Figure 3　Conduit type gate valve

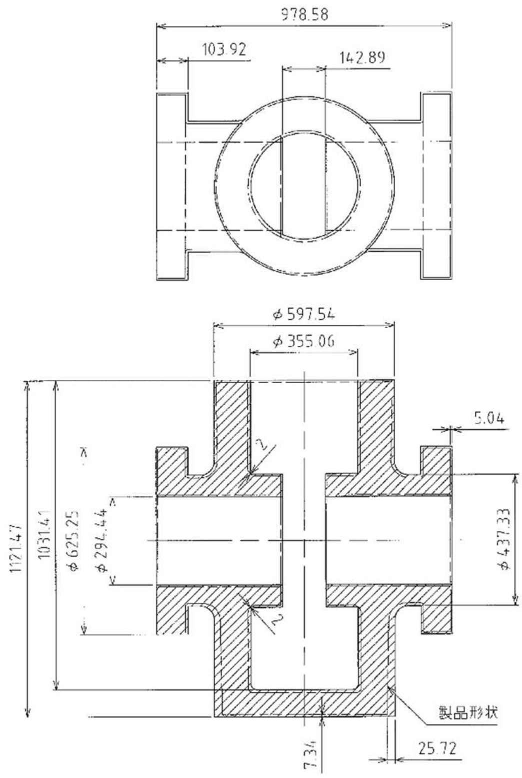


Figure 4　Configuration of the valve body

4. Capsule preparation and powder filling

4.1 Capsule preparation

The capsule for the valve body was prepared using 3.2 mm thickness steel plates. After cutting and bending the plate, it was assembled by manual welding. **Figure 5** shows the welding operation of the core.

Since the HIP process needs one capsule for each product, two capsules were prepared

Figure 5　Assembling of the capsule

4.2 Powder filling

Powder filling was performed using the vibration device that was newly installed for this trial production. The estimated filling density was 72%, whereas the actual densities were 70.6% for No.1 and 69.0% for No.2 respectively.

4.3 Sealing and degassing

A nozzle was connected to the vacuum pump and other nozzles were sealed by inserting plugs. After degassing the connected nozzle was caulked and disconnected.

5 HIP treatment

5.1 HIP conditions

HIP treatment was performed by the Giga-HIP device of MTC.
Before HIP treatment of the valve body, a preliminary test using the same material samples was made to find the optimum HIP treatment conditions. Based on such results, the treatment conditions were decided to be a temperature of 1,150°C, a pressure of 118 MPa and holding time of 6 hours. The heating time from room temperature to the holding temperature is 4 hours and the cooling time is 6 hours.

5.2 Shrinkage due to HIP treatment

Table 2 shows the actual shrinkage ratio (=1-(dimension after HIP/dimension before HIP)) of each part due to HIP treatment. The ranges of the ratio are from 9.7 to 10.3% for No. 1 and 10.4 to 11.1% for No. 2. Because the shrinkage ratios are almost constant in each case it can be concluded that the powder was filled uniformly in every part of the capsule.

Table 2 Shrinkage rate

Product No.			No.1	No.2
Filling rate	Designed		72.0%	
	Actual		70.6%	69.0%
Shrinkage rate	Theoretical rate based on the actual filling rate(*)		11.0%	11.6%
	Actual	Hight	10.0%	10.9%
		Width	10.2%	10.6%
		O.D of body	10.3%	10.4%
		I.D of body	10.3%	11.1%
		O.D of flange	10.0%	10.8%
		I.D of flange	9.7%	10.5%
		Average	10.1%	10.7%

(*): Theoretical shrinkage rate = 1- (cube root of actual filling rate)

6 Pickling and heat treatment

6.1 Pickling

The PM HIP NNS process needs to remove the capsule after HIP treatment. There are generally two methods for removing capsule. When the whole surface of the product is finished by machining the capsule is removed by finish machining simultaneously. However, when any part of the surface cannot be finished by machining the capsule has to be removed by pickling. Since some surfaces of this valve body cannot be finished by machining pickling was performed before heat treatment. **Figure 6** shows the appearance after pickling.

Figure 6 After pickling

6.2 Heat treatment

After removing the capsule, solution heat treatment was performed by a heat treatment furnace of Shimoda under the following conditions;

Heat treatment condition: 1,100°C x 4hr → water cooling

In order to prevent σ phase, this heat treatment furnace is equipped with an automatic rapid water cooling mechanism (see **Figure 7**). According to the time measurement when cooling the valve bodies, the time from full opening of the gate to start cooling was 28 seconds. The NORSOK standard (refer to clause 8.1) requires that the time to start of water cooling shall be 60 seconds or less. It was confirmed that our furnace has sufficient performance.

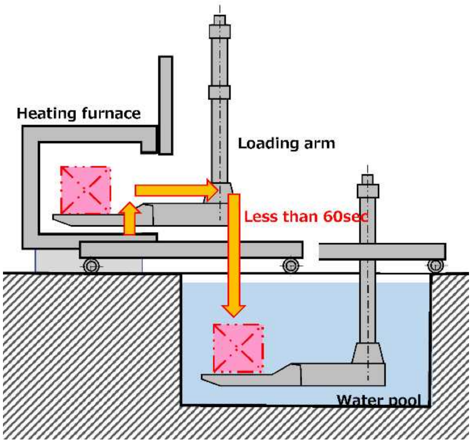


Figure 7　Automatic cooling

7 Machining

A product was finished by machining. Since the HIPed blank is near to the final shape, only the following surfaces were machined.

(1) Flange: Contact surface, outer surface, inner surface and bolt holes.
(2) Upper side of the body: Outer cylindrical surface (approximately 80 mm from the end), inner surface and screw holes at the upper end.
(3) Lower side of the body: Bottom surface.

No problem was found on machinability.
Figure 8 a) shows the appearance after machining, and Figure 8 b) shows the final appearance after coating.

a) After machining

b) Finished valve body

Figure 8　Appearance of the product

8 Investigations of the properties

8.1 Applicable standard

The investigations were conducted according to the NORSOK standard which is a certification standard for parts for offshore oil and gas plants. The steel grade is “HIP product ASTM A988 UNS S32505” specified in NORSOK standard MDS D54[3).

8.2 Investigation items

The following items were investigated;

(1) Tensile properties at room temperature
(2) Impact properties at low temperature (- 46°C)
(3) Ferrite content
(4) Microstructure
(5) Corrosion resistance (Ferric chloride corrosion test)

8.3 Investigation results

8.3.1 Sampling locations

A product other than finished one was sampled for the investigations. Specimens were taken at the location and the direction shown in **Figure 9**. In the figure, the symbols represent the upper body part (UB), the pipe part upper side (P1), the pipe part lower side (P2), the lower body part (LB) and the bottom part (B), respectively. Z is the axial direction, X is the direction perpendicular to the axis, and T is the circumferential direction.

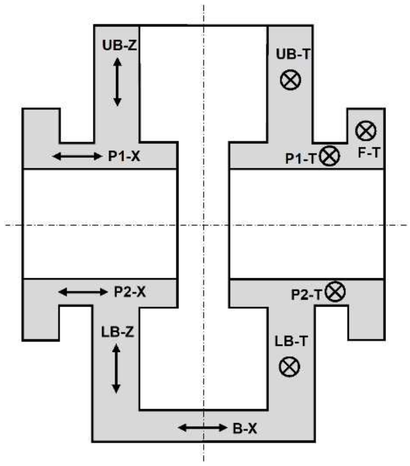


Figure 9 Sampling location and direction

8.3.2 Tensile properties

The results of the tensile test are shown in **Figure 10**. Not only all the results satisfy the requirements of NORSOK standard but also they are almost constant regardless of the sampled location and direction. Such isotropy of the properties is an important feature of HIPed product.

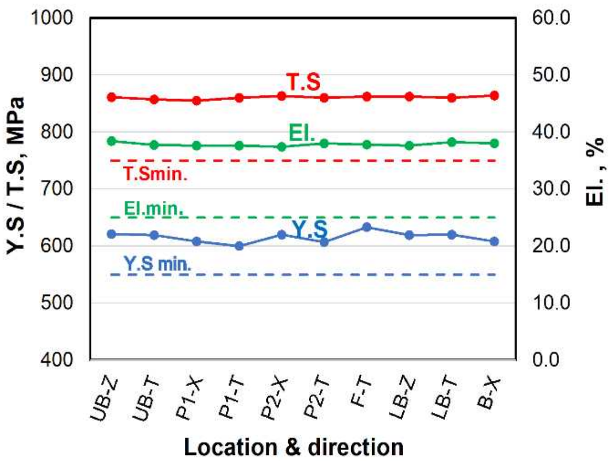


Figure 10 Tensile test results

8.3.3 Impact properties

Figure 11 shows the results of 2mm-V notch Charpy test at -46°C according to the requirements of NORSOK standard. The results satisfy the requirements of NORSOK with sufficient margin. Moreover, the variation among individual values (X) under the same condition is less than usual. This proves the stable properties of HIPed products.

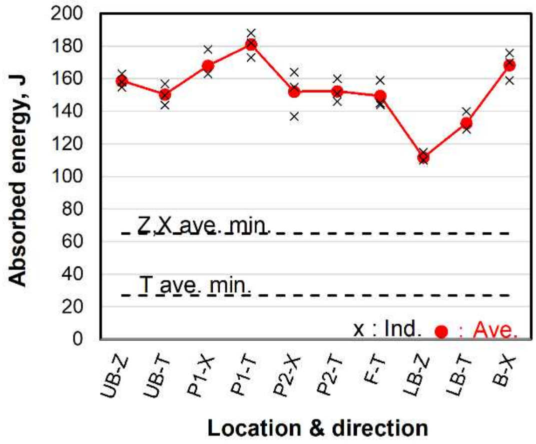


Figure 11　Charpy test results

8.3.4 Microstructure and ferrite content

NORSOK standard requires that no detrimental intermetallic phase is found in the microstructure and the ferrite content is to be 40-60%.

As shown in **Figure 12**, every structure consists of duplex fine grain structure. The grain sizes are almost same regardless of the investigated location. Moreover, as a matter of course, the metal flow (direction of the structure) which is often observed in forged products is not observed at all.

Table 3 shows the conclusion of these investigations**.** All the results are satisfactory.

8.3.5 Corrosion resistance

A ferric chloride corrosion test was conducted in accordance with the requirements of NORSOK. Since the corrosion weight loss is less than 10% of the required value as shown in Table 3, it is confirmed that this product has excellent corrosion resistance.

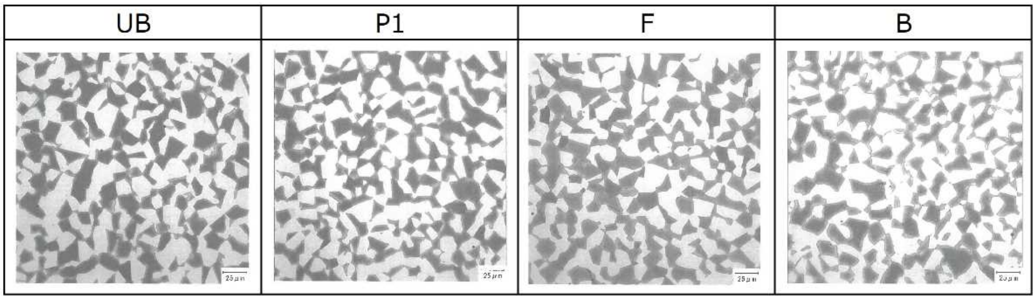


Figure 12　Microstructure

Table 3　Microstructure and corrosion test results

Location	Microstructure			Corrosion test ASTM G48 Method A	
	Inter-metallic phases	Photo.	Ferrite content (%)	Pitting	Weight loss (g/m^2)
NORSOK requirement	Not observed	(ref.)	40-60	Not observed	≦4.0
UB	No	Fig.11	42.9	No	0.3
P1	No		44.7	No	0.4
F	No		43.5		
B	No		43.8		

8.3.6 Conclusion on NORSOK requirements

As mentioned above, all of the NORSOK requirements have been satisfied. Therefore it can be concluded that the product manufactured by HIP process has satisfactory properties as "HIP product ASTM A988 UNS S32505" of NORSOK MDS D54.

9 Conclusion

As a result of the trial production of valve bodies for subsea oil and gas plants by PM HIP NNS process, the followings are concluded;

(1) The powder filling density was around 70% thanks to the newly introduced vibration device. In addition, the shrinkage rates by HIP treatment were almost constant at every part. It means that the powder was filled uniformly into every part of the capsule.

(2) Solution treatment was made by the newly installed heat treatment furnace equipped with an automatic cooling mechanism. The time from discharging from the furnace to start cooling was 28 seconds. This is much less than the requirement by NORSOK, that is, "60 seconds or less".

(3) A product was sampled for the investigations of properties. The results of the tensile test and impact test met the requirements of NORSOK standard. Moreover, all the values are quite uniform not depending on the sampled locations and directions. This is an important advantage of HIPed products.

(4) The microstructures were duplex fine grain structures. The grain sizes are uniform at any section. No detrimental intermetallic phase was observed. The corrosion resistance was sufficient.

(5) As a conclusion, the valve body manufactured by PM HIP NNS process satisfied all NORSOK requirements for the products for subsea oil and gas plants.

References

1) Hiroshi Urakawa, et al: PM HIP NNS Process for Valve Bodies Made of Grade 91 Material, Shimoda Technical Report No.E-3, Dec. 2018
2) ASTM A988-15, Standard Specification for Hot Isostatically-Pressed Stainless Steel Flanges, Fittings, Valves ,and Parts for High Temperature Service, S32505
3) NORSOK standard M-630, Material Data Sheet, MDS D54 Rev.5, Oct. 2013