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HIP Process of a Valve Body to Near-Net-Shape using Grade 91 Powder

Toyohito Shiokawa[1,a,*], Hiroshi Urakawa[2,b], Mitsuo Okuwaki[1,c], Yuto Nagamachi[3,d]

[1]970 Shimoise, Hayashida-cho, Himeji-shi, Hyogo-ken, 679-4233, JAPAN

[2]250, Ryusen-cho, Aioi City, Hyogo, JAPAN

[3]713 Shake-aza, Narihira, Ebina-shi, Kanagawa-ken, 243-0424, JAPAN

[a]tshiokawa@kinzoku.co.jp, [b]h.urakawa@shimoda-flg.co.jp, [c]okuwaki@kinzoku.co.jp, [d]ynagamachi@kinzoku.co.jp

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Abstract. Materials used for steam piping of power plants are exposed to high temperatures and high pressures over long periods of time. As a consequence, forged Grade 91 alloy steel is commonly chosen to meet these demands. However, complicated structures such as a valve body are often machined from large forged blocks resulting in long machining time and the material weight being heavy. Therefore, by manufacturing a valve body with near net technology, both the time and material weight can be reduced. This paper will present 1) a survey of the dimensions of a valve body HIPed to a near net shape, 2) an investigation of the mechanical properties of Grade 91 powder, 3) a comparison of the structure of a HIPed product and a forged product, 4) The machining time and material weight of a near net shaped (NNS) product by HIP compared to a forged product. This paper will illustrate that the NNS product was able to reduce the machining time by 30% and the material weight by 40% less than when machining from a forged product.

Introduction

Grade 91, which is a high chrome steel, has excellent high temperature strength and is therefore used in steam piping of power plants which are exposed to high temperatures and high pressures for long periods of time. Due to this environment heavy loads are placed on the piping. Most of these parts are currently manufactured by forging, and large parts such as a valve body are assembled and welded using multiple small parts, or are machined from one large block. However, the seam areas, such as the welded portion, have a lower strength to the base metal. In order to prolong the life of the steam piping, there is a desire to reduce the number of welds and fabricate an integrated structure by machining. Since the integrated structure has a complex shape, it must be machined from a large block, machining time and material weight increases, which is expensive. Components produced with PM/HIP can be produced very near final shape, resulting in reduced component weight, reduced machining, reduced energy, and reduced waste from post-process machining. [1] This paper will present 1) a survey of the dimensions of a valve body HIPed to a near net shape, 2) an investigation of the mechanical properties of Grade 91 powder, 3) a comparison of the structure of a HIPed product and a forged product, 4) The machining time and material weight of a NNS product by HIP compared to a forged product.

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Method

Fig. 1 is the post HIP target shape dimensions. Fig. 2 is the capsule’s dimensions based on the post HIP target shape.The capsule designed had an extra 5mm excess thickness on each side and we assumed a packing density of 67%. The Circles in fig. 2 indicate an additional 20mm thickness to aid welding. The grey block in the centre indicates where we placed a mild steel block which also aided the welding process of the capsule. Since the capsule rigidity (thickness) greatly affects the shape of the HIPed products and the deformation during densification becomes more isotropic when the capsule materials are thin and the same thicknesses are used [2] the capsule material was constructed from mild steel with a thickness of 3.2mm.

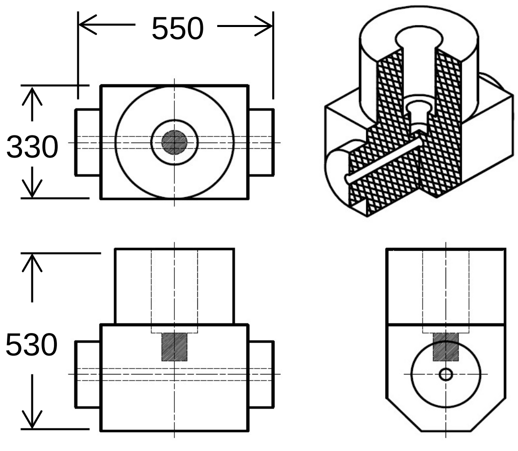

Fig. 1 Post HIP target shape

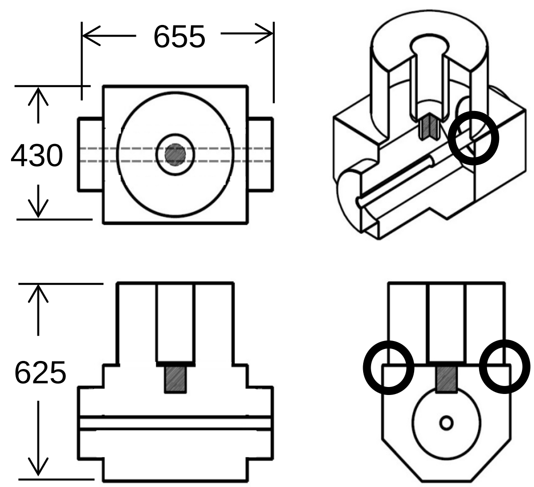

Fig. 2 Capsule shape

The Powder used was Grade 91; the chemical composition is shown in table 1. The Actual packing density that was reached was 67.4%. The capsule was then HIPed at 1200 degrees Celsius and 118 megapascals. After HIP, the capsule dimensions were measured for a survey of the near net shape valve body by HIP.

Table 1. Chemical composition

C	Mn	P	S	Si	Cr	Mo	Ni	V
0.10	0.39	0.011	0.005	0.40	8.77	0.90	0.17	0.25
Cd	Cu	Al	Ti	Sn	W	N	As	Zr
0.08	0.09	0.00	0.003	0.003	0.00	0.050	0.001	0.002
Sb	Pb	O	N/Al > 24					
<0.002	0.00006	110ppm	Sb + Sn + As + Pb <0.0061%					

After the measurements were taken the capsule was removed from the HIPed product by machining and heat treated according to ASTM A989 and the following investigation was conducted.

- An investigation of the mechanical properties of NNS Grade 91
- A comparison of the structure of a HIPed product and a forged product
- A comparison of the machining times and material weights of both products.

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Results and Discussion

A survey of the dimensions of a near net shape valve body by HIP

A comparison of the dimensions before and after HIP and the shrinkage ratio of the capsule were calculated. Shrinkage ratio = {(|dimensions before HIP - dimensions after HIP|)/dimensions before HIP processing} x 100% were calculated. The target shape and the actual shape were compared and the difference was investigated. The difference between the target shape and the post-HIP shape was calculated as {(| target dimension - post-HIP dimension minus capsule wall thickness |) / target dimension} x 100%. Fig. 3 and table 2 show the measurement positions and results. In table 2 the dimensions of E show the figures with the 20mm 'extra welding support' *removed. T*he bottom surface was under the target shape of 6.7mm. The upper side surface and the intermediate surface were both around 20mm.The shrinkage rate of the capsule was 4.3 to 11.8%. The shrinkage ratios of C and D were as low as 4.3 and 5.1%. This was due to the small diameter which helped capsule stiffness and decreased the shrinkage rate. The outer sides were 10.9 - 11.8% and they contracted almost equally. The difference from the overall target size after HIP is now only 3.2 to 5.5 percent. This was the first time to manufacture this kind of valve body. Our next goal is to keep the difference between the shape after HIP and the target shape within 2%.

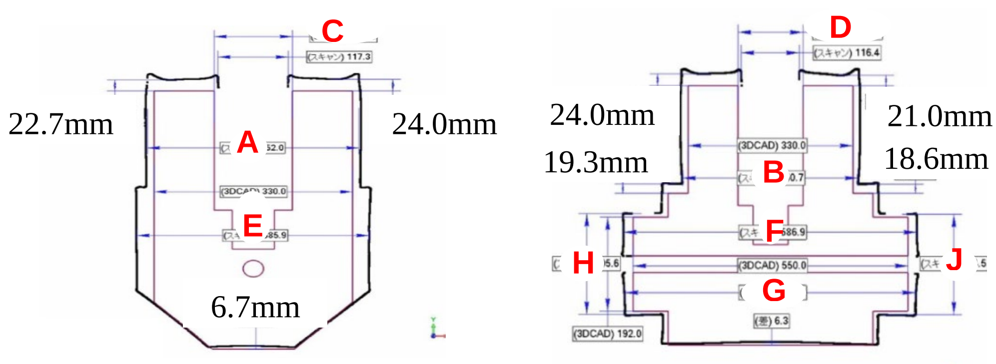

Fig. 3 The measurement positions and results.

Table 2 Dimension measurements results

	A	B	C	D	E	F	G	H	J
Before HIP [mm]	396.5	396.5	122.6	122.6	396.0	658.9	659.0	231.7	231.4
After HIP [mm]	352.0	350.7	117.3	116.4	350.5	586.9	581.3	205.6	204.5
Shrinkage ratio [%]	11.2	11.6	4.3	5.1	11.5	10.9	11.8	11.3	11.6
Goal shape [mm]	330	330	130	130	330	550	550	192	192
Error [%]	4.7	4.3	4.8	5.5	4.3	5.5	4.5	3.7	3.2

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An investigation of the mechanical properties of NNS Grade 91

The Capsule was removed from the HIPed product by machining and heat treated according to ASTM A989. After heat treatment, the HIPed body was cut and we performed a tensile test at room temperature, an elevated temperature tensile test, and a Brinell hardness test. The tensile test samples at room temperature and the elevated temperature tensile test samples were taken from each of the places indicated in fig. 4. These samples were taken from two directions, one in the axial direction and the other in the circumferential direction.

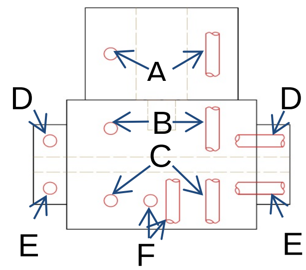

Fig. 4 Position of both Tensile Tests Samples

Table 3 shows the tensile test results at room temperature. The Tensile test was conducted to investigate 0.2% proof stress, tensile strength, elongation value, and reduction of area value. A to F are the average values of the tensile test results in the axial direction and circumferential direction. There is almost no difference between the tensile test results in the axial direction and the circumferential direction. The average displayed is the average for all of the samples. All tests were higher than the standard values of ASTM A989.

Table 3. The tensile test results at room temperature

	A	B	C	D	E	F	Average	ASTM A 989
0.2% proof stress [MPa]	475.0	474.3	474.5	472.5	474.5	474.3	474.2	415
Tensile strength [MPa]	648.5	649.3	645.8	645.5	646.5	644.8	646.7	585
Elongation [%]	29.2	29.8	28.5	28.3	28.5	28.7	28.8	20
Reduction of area [%]	71.1	71.2	70.2	71.2	70.8	70.7	70.9	40

Fig. 5 shows the results from the elevated temperature tensile test. These tests were also performed at intervals of 100 degrees Celsius at a range of 100 degrees Celsius up to 700 degrees Celsius. From 400 degrees Celsius the 0.2 percent proof stress and tensile strength tests results were weaker. However, the results for the elongation and reduction of area tests were more ductile.

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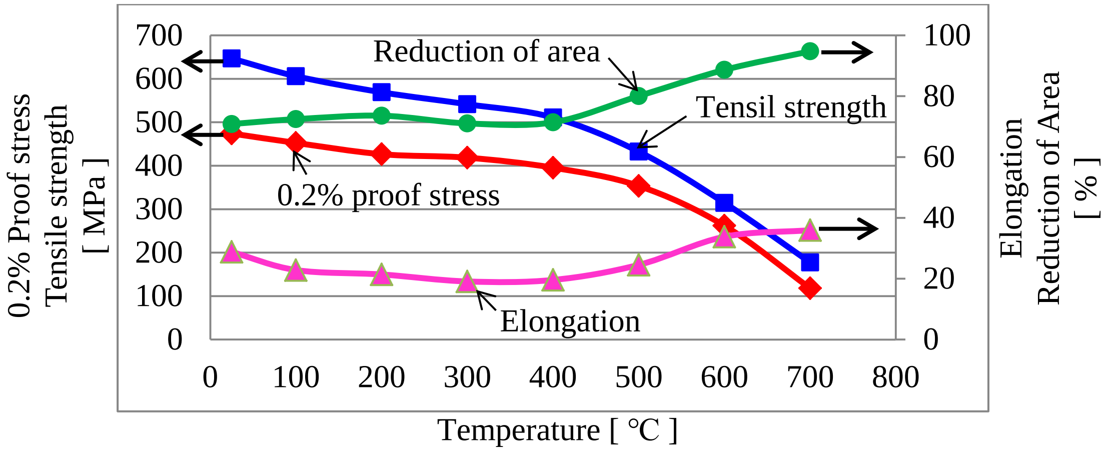

Fig. 5 The results from the elevated temperature tensile

Fig. 6 is the Brinell hardness measurement results. The hardness of the HIPed body was HB 197 to 205, and there was almost no difference between the surface layer and the interior. All the mechanical properties satisfied ASTM A 989 standard. Currently 3,000 hours and 10,000 hours creep tests are also conducted.

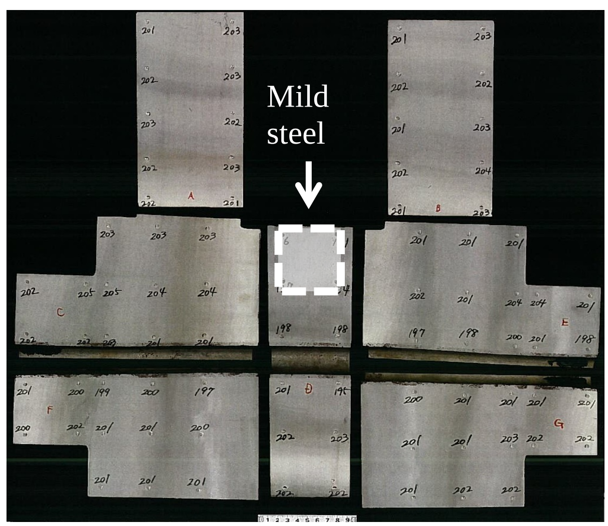

Fig. 6 The Brinell hardness measurement results

A comparison of the structure of a HIPed product and a forged product

Microstructure observation of the HIPed product after the heat treatment was carried out to investigate the difference between the structure of the HIPed product and the forged product.

Nonmetallic inclusions of HIPed products were also measured. Fig. 7 shows the microstructure of grade 91. On the left is the HIPed product and on the right is the forged product. The forged product has a distinct visible fiber flow. However, in contrast the HIPed product’s fiber flow is not visible. The HIPed product’s microstructure is finer than the forged product’s. Fig. 8 shows the microstructure photographs of the surface area and the internal area of the HIP product.

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There were no differences between the surface area (after capsule removal) and the internal areas.

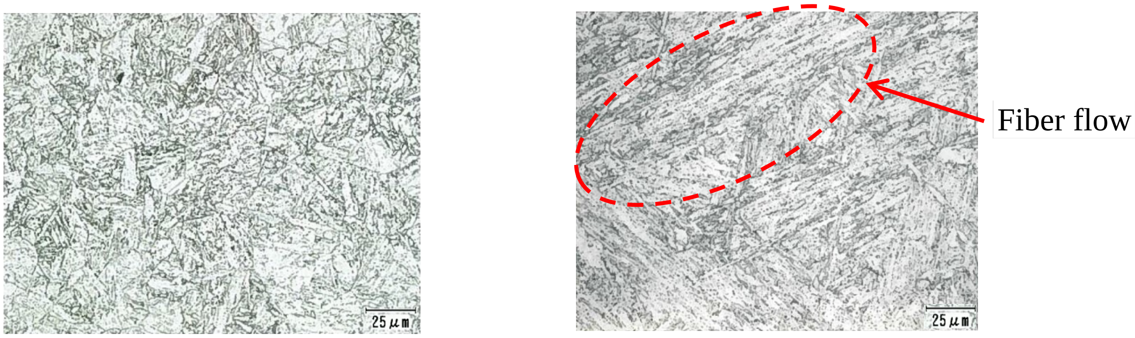

Fig. 7 The microstructure of the HIPed product (left) and the forged product

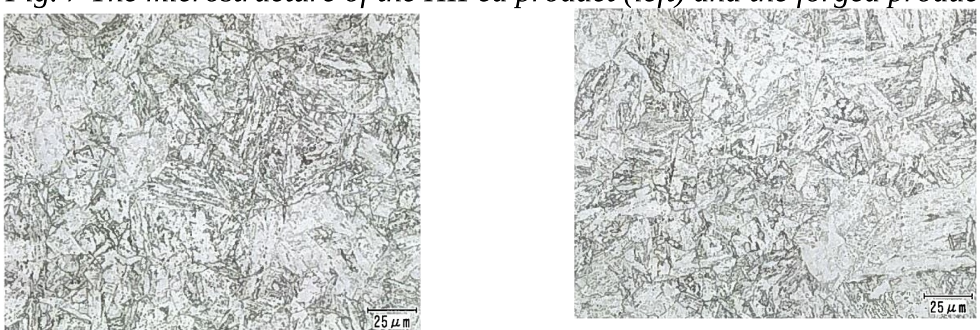

Fig. 8 The microstructure of the surface area (left) and the internal area (right) of the

Table 4 Comparison of a HIP-NNS product and a forged product			
	Forged	HIP-NNS	Reduction ratio (%)
Material weight [kg]	900	536	40
Machining time [hours]	100	70	30

The non-metallic inclusion measurement was conducted according to ASTM E 45 A. In the HIPed product there is a small amount of grained oxide but there is no sulfide, alumina, or silicate and as such it is very clean for a HIPed product. These results show that there is no difference in mechanical properties between the outside and the inside of the HIPed product.

Machining time and material weight comparison

A comparison of the machining time for the forged product and the HIP-NNS product was conducted using the following fomula. Reduction of machining time = (|machining time from forged block - machining time from HIP NNS product |) / machining time from forged block x 100%

The fomula for a material weight comparison between the forged product and the HIP-NNS product was calculated by the following formula. Reduction of material weight = (|forged block weight - HIP NNS product weight |) / forged block weight x 100%

Table 4 below shows the comparison result. The forged material weight is 900 kilograms in contrast to the much lighter HIPed NNS at 536 kilograms. The machining time for a forged product is 100 hours but the HIPed NNS product is as low as 70 hours. This means that the

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HIPed NNS product can offer us a 40% reduction in material weight and a 30% reduction of machining time compared to a forged product.

Conclusions

In conclusion we can see that the difference from the overall target size was *only* 3.2 to 5.5 percent and this was mainly due to the capsule design and construction. We can also see that we achieved a better than ASTM standard for all related tests. Thirdly the HIPed NNS product’s microstructure is homogeneous across all thicknesses which means there is almost no difference in the mechanical properties throughout the product. And significantly the manufacturing of a valve body using HIP NNS technology provides a 40% reduction in material weight and a 30% reduction of machining time compared to a forged product underlining the benefits to both the environment and the manufacturer.

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