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PM-HIP Manufacturing Method for Nuclear Reactor Components

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1. Introduction

It is not so long since powder metallurgy became considered as a candidate manufacturing technology for nuclear components, even for the large pressure vessel. Powder metallurgy has been applied to produce various components mostly in complex shape but of relatively small in size, especially with the materials with high melting points such as refractory metals, ceramics and so on. The technology is well known to bring a uniform and fine microstructure due to the low consolidation, either sintering or pressing, temperature mostly below the melting temperature. Although powder metallurgy has been regarded as a good technology for producing the relatively small objects, it was proposed for large nuclear reactor components to take a detour around the conventional and well-established nuclear reactors manufacturing methods such as melting and hot forging that require large facilities [1].

Since Powder Metallurgy-Hot Isostatic Pressing (PM-HIP) method was proposed for the manufacturing of Small Modular Reactor Pressure Vessel, having been claimed to be beneficial in terms of the cost and the delivery time compared with the conventional methods, there has been much effort to utilize the technology to the nuclear reactor components [2, 3].

In this study the development of PM-HIP technology for the nuclear reactor components materials, including austenitic stainless steels, nickel-base alloys, ferritic-martensitic steels as well as SA 508 low alloy steel, are surveyed [4, 5, 6]. And an experimental result on the PM-HIP SA 508 Gr. 3 low alloy steel is presented. Uniform distribution of the hardness values across one PM-HIP specimen each is verified, and a distinct different range of the hardness values between two kind of PM-HIP steel samples that were prepared through two different powder preparation routes is also demonstrated.

2. Methods and Results

Chemical compositions of two SA508 low alloy steel powders and the mother steel alloy from which the powders had been prepared are shown in Table I. To produce the spherical low alloy steel powders a couple of blocks of the mother SA 508 Gr. 3 Cl. 1 steel were melted again and atomized, and two different atomization routes of the inert gas atomization (GA) and the electrode induction melting gas atomization (EIGA) were utilized. The steel powders under 200 micrometers in diameter were collected by sieving, and HIP processed at 1020^{o}C for 4 hours under the pressure of 100 MPa, following the canning and the degassing steps. The size of the HIP specimen was 80 mm in diameter and 150 mm long each after decanning and machining.

Longitudinal and transverse sections of HIP specimen were prepared, and the microhardness was measured under the load of 2 kgf holding for 10 seconds using Buehler's Wilson™ VH 3300 at 100 points with 8 mm intervals and at 60 points with 5 mm intervals on each sectioned and polished specimen surface, respectively.

The measured microhardness values are displayed in Fig. 1. The measured values appear relatively uniform all through on a specimen whichever sectioned transversely or longitudinally; but also revealed a distinctively different range of the hardness values between PM-HIP (GA) specimens and PM-HIP (EIGA) ones (E1 vs. AA13).

Hardness difference between PM-HIP (GA) samples and PM-HIP (EIGA) ones would attributes to the different carbon contents between them. Higher carbon content in PM-HIP (GA) sample, probably of the contamination from the melting crucible, could make stronger precipitation hardening effect from more cementite phase as well as higher solid solution hardening effect compared with the other one with lower carbon content.

Table I: Chemical composition of two PM-HIP and one conventional SA 508 Low Alloy Steels (wt%)

		C	Mn	P	S	Si	Ni	Cr	Mo	V	Cu	Al
ASTM	min		1.20				0.40		0.45			
	max	0.25	1.50	0.025	0.025	0.40	1.00	0.25	0.60	0.05	0.02	0.030
Conventional (Forged)		0.20	1.34	0.007	0.002	0.20	0.89	0.20	0.50	0.002	0.02	0.02
PM-HIP (GA)		0.51	1.07	0.005	0.004	0.345	0.87	0.198	0.51	0.002	0.023	0.008
PM-HIP (EIGA)		0.206	1.13	0.006	0.003	0.214	0.87	0.201	0.50	0.002	0.023	0.018

During the cooling stage of HIP process carbon content could substantially affect the kinetics of bainitic transformation of low alloy steel [7], and the range of cooling rate during HIP process is usually so limited that the strict control of chemical compositions shall be vital to acquire a desired hardness value or mechanical properties of PM-HIP components, especially in case of the thick or large component production.

On the other hand, the heat-treated PM-HIP sample shows nearly 15% reduction of the hardness values (AA13 vs. AA14), approaching those values of the conventionally produced and heat-treated SA 508 Gr. 3 Cl. 1 low alloy steel specimen.

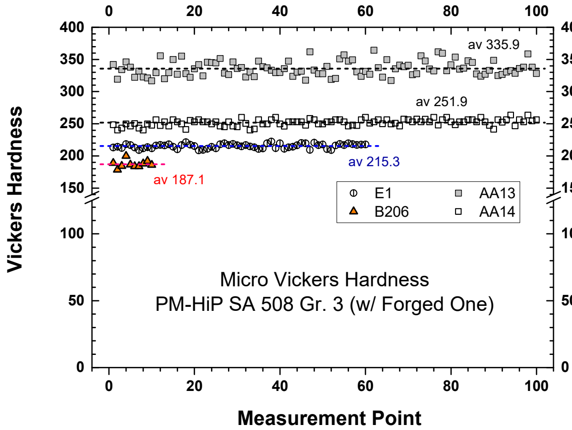

Fig. 1. Micro Vickers hardness of different PM-HIP SA 508 Gr.3 low alloy steel samples, along with a conventionally produced one (B206; forged & heat-treated)

3. Summaries

PM-HIP SA508 Gr.3 steel samples were prepared by melting and atomization of the conventionally produced mother SA508 steel alloy, and hot isostatic pressing. To produce the steel powders the inert gas atomization (GA) and the electrode induction melting gas atomization (EIGA) methods were used.

Micro Vickers hardness was measured on 60, or 100 points on the sectioned and polished surface of PM-HIP specimens. Uniform hardness values were confirmed on each specimen surface of PM-HIP (GA) samples and PM-HIP (EIGA) ones, respectively. Distinctly different hardness ranges were also observed between two kinds of the samples, and the difference is mainly attributed to the different carbon content.

After heat-treatment of PM-HIP (EIGA) sample, the measured hardness values showed a reduction of nearly 15%, approaching those values of the conventionally produced and the heat-treated SA 508 Gr. 3. Cl. 1 low alloys steel sample.

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