Fracture Analysis for the Valve disc of Nickel Based Superalloy prepared by Hot Isostatic Pressing

Dungui Zuo, Zhongwei Zhang*, Yunting Lai and Guodong Zhang
Su Zhou Nuclear Power Institute Co., Ltd, Jiang Su, China

*Corresponding author: zhangzhongwei@cgnpc.com.cn

Abstract. The technology of hot isostatic pressing is combined with the mould control technology under high temperature and high pressure, which can make the powder material quickly and completely shape the complex parts of the forging parts. At the same time, the controllable loading temperature and pressure can be used to realize the preparation and regulation of the material. HIP technology has been widely used in nickel-based alloy valve spheres, valve seats, valve discs and so on. The reasons leading to fracture for the globe valve disc of nickel based superalloy prepared by HIP was analyzed by means of morphology analysis, mechanical properties test, hardness test, metallographic test and other detection means. The results show that there are more black massive carbides, original powder outlines, residual dendrite structure can be seen in the base body structure, and resulting in greater brittleness and poor impact resistance, the fracture failure first occurs under the action of several impact forces generated by the valve action, which in turn causes the sealing gap between the valve disc and the valve seat to change, resulting in the drainage of water from the high pressure side through the gap to the low pressure side, and the gap on both sides metal constitutes erosion.

Keywords: Hot isostatic pressing, globe valve, fracture, erosion

1. Introduction
The hot isostatic pressing technology was developed by the American Battelle laboratory in 1955, which was first used for the diffusion bonding of fuel elements in the process of atomic energy reaction. With the implementation of hot isostatic pressing technology, its application range has been continuously expanded. At present, hot isostatic pressing technology has been widely used in nickel-based alloy valve spheres, valve seats, valve discs, etc [1]. The reasons leading to fracture for the globe valve disc of nickel based superalloy prepared by HIP was analyzed in this paper, finds out the cause of failure, and provides an effective basis for the subsequent safe and stable operation of the power unit. The failure globe valve is located in the drain line upstream of the main steam isolation valve. Each drain line is equipped with a pneumatic isolation valve and a one-way check valve. Pneumatic isolation valves are only used in steam line warming or thermal shutdown. The valve operating environment of the valve was gas-liquid two-phase hydrophobic, and temperature and pressure are 282.14 °C and 6.63MPa. The structure of the pneumatic globe valve is shown in Figure 1. The working mechanism can be describe as follows: the opening and closing of the valve is to use compressed air and the spring and disc gravity. The material
of the valve seat is HIP nickel-based alloy (Gr.5), the material of the valve disc is HIP nickel-based alloy (Gr.4), the sealing gasket material between the valve seat and the valve body is expanded graphite.

![Diagram of pneumatic globe valve](image)

**Figure 1.** Diagram of pneumatic globe valve

2. **Observation results**

2.1. **Visual inspection**

![Macroscopic morphology of valve seat](image)

**Figure 2.** Macroscopic morphology of valve seat
(a) Fracture zone A and B, (b) Fracture zone B and C, (c) Damaged surface, (d) Damaged surface

When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications,
they must ask the corresponding publishers to grant them the right to publish this material in their paper. Figure.2 shows the macroscopic image of the damaged valve seat. It can be seen that the brittle fracture occurred in the contact part between the valve seat and the graphite gasket, and the damaged zone had fractured into three parts (labelled A, B, C). The fracture in A zone is completely separated and B zone is missed. It can be seen that there is an obvious crack adjacent to the fracture B zone (Figure.2(b), by arrow), which the fracture seat falls off when the valve seat is taken out of the valve cage. The sealing surface of the valve seat at the corresponding position of the fracture A zone is damaged, as shown in Figure.2(d). The damaged surface is very rough and irregular.

As Figure.3 shows, there are many obvious damages on the sealing surface of the valve disc, which are fan-shaped, loose metal accumulations in the lower part, obvious sharpness in the upper part, smoother bottom, and no obvious corrosion characteristics. In conclusion, failure of valve disc should be typical Liquid Impact Erosion [2].

![Figure 3. Macroscopic morphology of valve disc](image)

2.2. Chemical composition of the valve disc and valve seat

The chemical analysis on the damaged valve disc and valve seat are carried out, and its results are presented in Table 1. The result shows that the chemical compositions are coincided with standard specification CY-40 [3].

|       | C  | Si | Cr  | B   | O   | Fe  | Ni   |
|-------|----|----|-----|-----|-----|-----|------|
| disc  | 0.35 | 2.18 | 14.26 | 2.01 | 0.0088 | 9.68 | 77.55 |
| seat  | 0.32 | 2.97 | 15.24 | 1.54 | 0.0080 | 9.96 | 81.17 |
| Specified | ≤0.40 | ≤3.00 | 14.0~17.0 | - | - | ≤11.0 | - |

2.3. Microstructure examination

Microstructure examination of the damaged valve disc and valve seat were cut along a plane on transversal cross-sections (as seen in Figure.4). As shown in Figure.5, the Microstructure of the valve disc is composed of white γ matrix and gray fine γ’ phase, more black massive carbides, and the original powder outline and a small amount of white (γ+γ’) eutectic can be seen. The Microstructure of the valve disc is composed of white γ matrix and gray fine γ’ phase, black massive carbides in the structure, more original powder outlines and residual dendrite structure can be seen.
Figure 6(a) presents typical Liquid Impact Erosion morphological characteristics [6], which is the damage location basically shows the different size of the upper and lower, and the direction of erosion is consistent with the flow direction of the internal medium. Figure 6(b) shows the fracture occurred at the corner part of the valve seat structure, which is the stress concentration part. Absence of plastic deformation on fracture indicate that the fracture is due to brittle fracture.

Figure 4. Microstructure examination samples of valve disc and valve seat
(a) Valve disc, (b) Valve seat

Figure 5. Microstructure of base material
(a) Valve disc, (b) Valve seat

Figure 6. Microstructure of damage location
(a) Valve disc, (b) Valve seat
2.4. Hardness

The core macro-hardness (HRC) of the damaged valve disc and valve seat were measured, whose values are listed Table 2. The results show that the hardness of the valve disc and the seat sealing surface are average values of 55.0HRC and 46.8HRC, which the difference between the valve disc and the seat sealing has clearly exceeded the requirements of standard NB/T 47044-2014 [4].

| Hardness | Value (measured) | Value (average) |
|----------|------------------|-----------------|
| Disc     | 55.0             | 55.0            |
| Seat     | 47.0             | 46.5            |

2.5. SEM observation on fractures

The microscopic features of the fractured valve seat was analysed by SEM observation. The results show as follows: Figure.7 gives fractographs of fracture origin region, propagation region and final fracture region of damaged valve disc. It can be seen that cracks propagate along the powder profile. Among them, fracture origin region is covered with a black cover, which the composition is mainly C and a small amount of O, Si, Fe, Ni and other elements. Judging from the test results and the composition of the expanded graphite, the black cover should be expanded graphite.

![Figure 7. SEM of the fracture valve seat](image)

(a) Crack initiation zone, (b) Crack propagation zone, (c) Final fracture zone

![Figure 8. SEM of crack initiation zone of the fracture valve seat](image)

The damaged surface of the valve disc in shown in Figure.9. The microscopic observation shows that there are four typical damaged regions on the sealing surface (marked A, B, C and D in Figure.9(a)). The damaged surfaces have Liquid Impact Erosion features, which are very rough and irregular, and the erosion direction are the same as the internal medium flow direction when the valve is opened, that is, the flow from the lower part to the upper part as a whole (Figure.9(b), (c), (d) and (e), by arrows).
3. Discussion

From the observations and examinations in Section 2, it is inferred that there were more original powder contours, black massive carbides, and more residual dendrites in the material structure. For powder metallurgy components, more powder contours together with black massive carbides and residual dendrites in the microstructure, which its presence will significantly reduce the overall impact resistance.
of the component and the binding force between the powders. [5-8]. The cracks propagate along the powder profile, which is consistent with the characteristics of the material structure, indicating that fracture is related to the poor organization of the seat material.

From the results of the morphology analysis and microscopic analysis, the fracture area of the valve seat is basically consistent with the erosion parts of the valve disc and valve seat. On this basis, it can be inferred that the metal gasket of the valve seat first breaks under several impact forces generated by the action of the valve due to poor microstructure, which leads to the change of the sealing clearance between the valve disc and the valve seat. When the valve is closed, due to the change of sealing clearance, the drain water can be ejected from the high pressure side (valve inlet side) to the low pressure side (valve outlet side) through the clearance, and the metal (disc sealing surface and seat sealing surface) on both sides of the clearance will be eroded.

4. Conclusions
The fracture surface of the valve seat is characterized by brittle cracking. The material is brittle and has poor mechanical property, which is related to the poor microstructure of the material. The damage of sealing surface of valve disc and valve seat is Liquid Impact Erosion damage, which is formed in the process of high pressure drainage quickly passing through the sealing surface.

Acknowledgments
This work was financially supported by National Key Research and Development Program of china (No.2017YFB0702200) fund.

References
[1] SHEN Qi-ming, YANG Jing, SHAN Xian-yu, Jan Westerlund.Development and Application of HIP Technology. Rare Metals and Cemented Carbides; 2003, 31: 33-38.
[2] Recommendations for Controlling Cavitation, Flashing, Liquid Droplet Impingement, and Solid Particle Erosion in Nuclear Power Plant Piping Systems. EPRI, 2004.
[3] Standard Specification for Castings, Nickel and Nickel Alloy. ASTM A494/A494M; 2017.
[4] Valves for power station. China Standard.; 2014
[5] XIE Jun, TIAN Su-gui, ZHOU Xiao-ming, LI Bo-song. Influence of microstructure on enduring properties of FGH95 nickel-base superalloy. Journal of Central South University (Science and Technology); 2012, 43: 2547-2553.
[6] Liu Xinling, Chen Xing, Hou Xueqin1, Tao Chunhu.Damage and Fracture Speciality of FGH95 Powder Superalloy. Rare Metal Materials and Engineering; 2009, 38 (7): 1179-1183.
[7] JIA Jian, TAO Yu, ZHANG Yi-wen, ZHANG Ying. Effect of ageing heat treatment on microstructure an mechanical properties of PM superalloy FGH95. Powder Metallurgy Industry; 2010, 20: 25-30.
[8] MENG Fanlai, TIAN Sugui, WANG Minggang, YU Xingfu, DU Hongqiang, SHUI Li, HU Zhuangqi. Influence of microstructure evolution on lattice misfit of a single crystal nickel based superalloy. Chinese Journal of Materials Research; 21: 225-229.