Development of High-performance Valve for Power Plants

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OVERVIEW: To improve the conservativeness and reliability of valves at fossil fuel and nuclear power plants, using Co (cobalt) base alloy, which is overlay-welded on the valve seat as a hard facing layer, is necessary. This use prevents the deterioration of valve performance due to corrosion, erosion and cracks. Concerning erosion damage sustained by the Co base alloy used for the valve seat under an environment of high dissolved oxygen (DO) and temperature, this phenomenon originally results from localized corrosion damage of the mesh-like eutectic carbide. Therefore, to improve valve performance and the characteristics of Co base alloy, we manufactured a new valve featuring valve seat alloy in which the eutectic carbide particles are dispersed in the metal matrix within the range of chemical composition of RCoCr-A. After evaluating the performance of the new valve, we confirmed its active role in improving valve performance. Especially, the amount of Co that escapes from the valve was found to be 1/10 or less compared with conventional valves. This demonstrates that a substantial decrease in the radioactive dose sustained by nuclear power plant personnel can possibly be achieved by adopting the new valve. Moreover, to demonstrate the excellent qualities described above in an actual operating plant, we performed tests comparing the conventional valve with the new one within the same environmental conditions for around one year. Our test results verified the outstanding ability of the new valve to withstand corrosion and erosion, compared to conventional valves.

INTRODUCTION

TO prevent the deterioration of valve performance at fossil fuel and nuclear power plants, Co base alloy [mainly RCoCr-A; AWS (American Welding Society) standard] is overlay-welded on valve seats as a hard facing layer (the valve seat overlay) for the valve-disc and body. However, the valve seat deteriorates and suffers damage over time, for example from corrosion, cracks and erosion, consequently requiring replacement. For these reasons, increased valve reliability and refinement has become a requirement; namely a valve seat material is required that is corrosion-resistant, strongly withstands erosion and displays mechanical sturdiness.[1)]

Concerning erosion damage sustained by the Co base alloy used for the valve seat under an environment of high dissolved oxygen (DO) and temperature, various reports have stated that this phenomenon originally results from localized corrosion damage of the mesh-like eutectic carbide. The metal microstructure of valve seat of Co base alloy is comprised of this mesh-like eutectic carbide as well as a dendrite core (matrix) surrounded by eutectic carbide. Therefore, to improve valve performance and the characteristics of Co base alloy, we manufactured a new valve featuring valve seat alloy in which the eutectic carbide particles are dispersed in the metal matrix within the range of chemical compositions of RCoCr-A. After evaluating the performance of this new valve , we confirmed its active role in improving valve performance. Moreover, we found that a substantial decrease in the radioactive dose sustained by nuclear power plant personnel can be achieved by adopting the valve. Here, the concept of the new valve that Hitachi has developed, and its characteristics are described (see Fig. 1).

BASIC CONCEPT OF NEW VALVE

The metal microstructure of the conventional valve seat has a dendritic structure with mesh-like eutectic

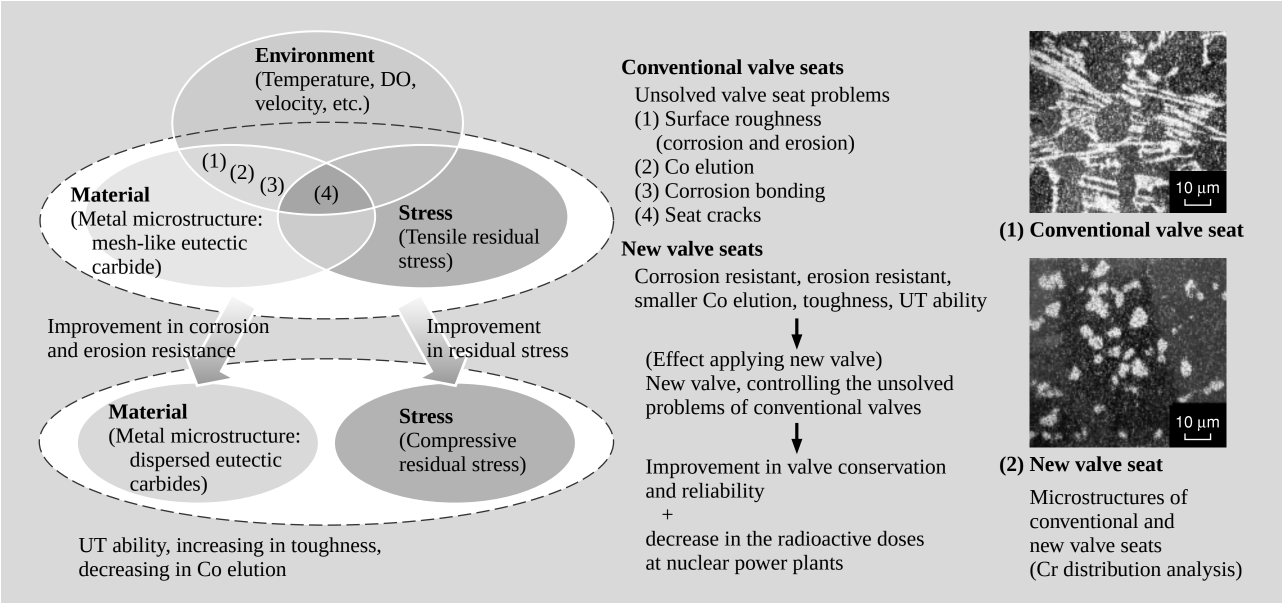


Fig. 1—Unsolved Valve Seat Problems, Corresponding Plan Due to New Valve and Effect Applying It.
Unsolved valve problems, especially valve seats, occur due to a combination of factors such as environment, materials and stress. New valve controls the occurrence of these phenomena by improving the corrosion-resistance, erosion and mechanical sturdiness, due to the metal microstructure changes and improvements in the stress.

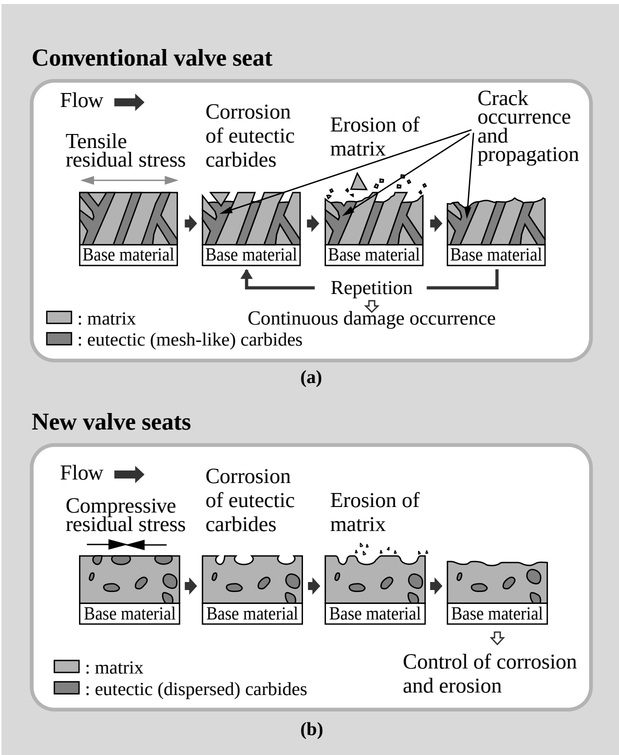


Fig. 2—Deterioration Mechanism of Conventional (a) and New (b) Valve Seats.
Damage to the conventional valve seat continually increases because of corrosion-resistant low eutectic carbide falling off. The new valve seat can control this damage.

carbide and a matrix. The process by which the conventional valve seat sustains damage can be explained as follows:

(1) The mesh-like eutectic carbide is subject to localized corrosion due to the dissolved oxygen in the fluid.

(2) The dendrite core is eroded due to the mechanical force of the fluid.

(3) Due to the repetition of both the chemical corrosion and mechanical erosion, the valve seat sustains ever greater degrees of damage.

As a means of measuring valve seat deterioration and damage, we considered the potential curbing of such chemical and mechanical corrosion and erosion by ensuring that the eutectic carbide particles be dispersed rather than forming mesh-like eutectic carbide. We believed that this would result in the ability to control collectively the occurrence of valve seat damages. Fig. 2 displays a comparison between a model subject to deterioration (damage mechanism model), featuring both the conventional valve seat and that of the new valve .

EVALUATION

Required Qualities

The required qualities for valve seats at fossil fuel

TABLE 1. Required Quality Evaluation for Valve Seats
Compared with conventional valve seats, the new valve seat performs very well in terms of all the qualities required.

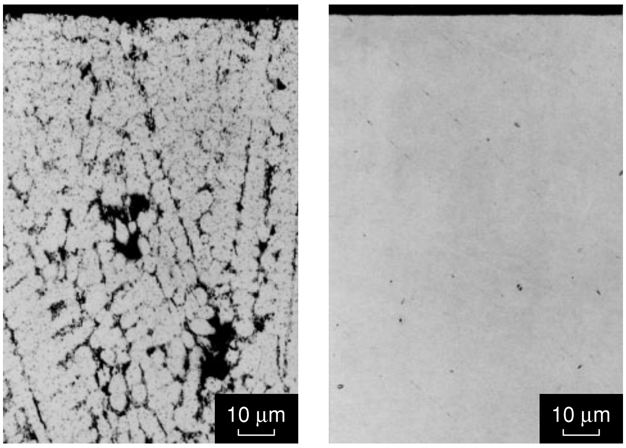
Required valve seat property*1	Evaluation test	Performance of new valve seat (compared to conventional valve)*2	Comments (test conditions, etc.)
(1) Corrosion resistance	Strauss test (JIS G 0575)	○ : Minor corrosion (see Fig. 3)	Test time: 72 h
	BWR-environment long-term exposure test	○ : Minor corrosion	Temperature: 290°C, DO: 8 ppm
(2) Wear resistance	Adhesive wear test	○ : Lower friction coefficient	Surface pressure: 200 MPa
	Motor-operated valve performance test (nominal diameter: 3B & 24B)	○ : Lower friction coefficient	Pressure: 7 MPa Temperature: 290°C
(3) Toughness (mechanical sturdiness)	Room-temp. Charpy impact test	○ : High toughness (Charpy value more than double)	JIS Z 2202 U-notch test specimen
	Thermal shock test (room temp. to 300˚C)	△ : No damage	—
(4) Residual stress	Residual stress measurements	○ : Compressive residual stress (conventional: tensile residual stress)	When hard-faced on carbon steel
(5) Erosion resistance	Underwater erosion test at room temp. (conformed to JIS R1615)	△ : Erosion damage equivalent compared to existing valve seats	—
	Cavitation erosion test (normal temp.) water erosion test using high-speed hot-water jets	○ : Minor erosion (se Fig. 4) Damage volume 1/10 or less	Temp.: 290°C, DO: 8 ppm, Velocity: 60 m/s
(6) Co elution	Co elution measurements	○ : Extremely low Co elution (see Fig. 5)	Temp.: 220°C, DO: 200 ppb
(7) Manufacturing process and nondestructive inspection	Ease of processing (machining & rubbing)	△ : Same processability	—
	Nondestructive inspection (especially UT to detect internal defects)	○ : Internal defects detection: possible (conventional valve cannot)	—

UT: ultrasonic test B: inch
*1 Items (1), (3), (4), (5), (6), and (7) must be improved in order to improve the conservativeness and reliability of valves and power plants.
*2 ○ : adequate or improved efficiency △ : virtually the same as conventional valve seats, meaning further improvement is not required.

and nuclear power plants are the following seven items:
(1) Corrosion-resistance: surface roughness of valve seat surfaces leads to leakage. Such operational degradation must be minimized.
(2) Wear resistance: friction drag is minimized.
(3) Mechanical sturdiness: mechanical sturdiness is necessary to prevent the occurrence of valve seat cracks and thus should be maximized.
(4) Lower residual stress: higher tensile residual stress is one of the factors causing valve seat cracks. Residual stress should be minimized as far as possible and where applicable, compressive residual stress is a preferable alternative.
(5) Erosion-resistance: erosion resistance under normal operating condition should be maximized, especially for fossil fuel and nuclear power plants, where the temperatures and dissolved oxygen level are very high.
(6) Co release control: small amount of Co release is preferable for nuclear power plants.
(7) Ease of manufacturing process and nondestructive inspection: ease of processing should be enabled and the detection of surface and internal defects facilitated through non-destructive examination.

Performance Evaluation

Having evaluated the performance results of the new valve concerning the seven qualities described above, we summarized the findings in Table 1. We found that compared with conventional valves, the new valve displays excellent performance in terms of all qualities required, and did not display any inferior quality. Our findings are listed below:
(1) The corrosion resistance of the new valve seat is far better than that of conventional valve seats (see Fig. 3).
(2) The friction coefficients of the new valve seat was found to be much lower than that of conventional valve seats.
(3) The absorbed energy of the new valve seat exceeded that of conventional valve seats by a factor of two or more.
(4) Residual stress of the conventional valve seat showed a high tensile stress in the lap direction. On the other hand, in the case of the new valve seat, compressive residual stress was found to occur in both

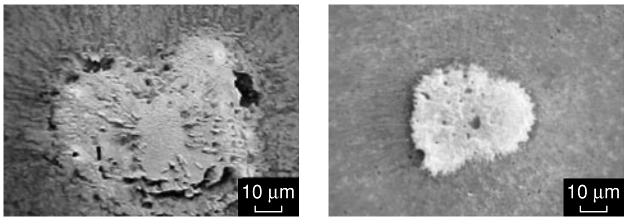


(a) Conventional valve seat **(b) New valve seat**

Fig. 3—Cross-sections of Valve seat after the Strauss Test.
Results of the Strauss test show that the corrosion resistance of the new valve seat is far better than that of the conventional valve seat.

the lap and diameter directions.
(5) In the erosion-resistance test conducted under conditions of high temperature and dissolved oxygen to simulate the actual operating environment, the erosion damage sustained by the new valve seat was found to be 1/10 or less than that of the conventional valve seat. (see Fig. 4)
(6) The amount of Co released by the new valve was found to be 1/10 or less compared with the conventional valve, implying a substantial reduction in the Co release rate is possible by the adoption (see Fig. 5).
(7) Concerning machining and rubbing, we found no significant difference in the ease of processing for manufacturing the new and conventional valves. We also found that UT of the new valve could help reveal internal valve seat defects, though such detection by using UT under the same conditions was impossible in the case of conventional valve seats.

Taking these appraisals into account, we conclude that new valve decreases likelihood of corrosion, erosion, valve seat cracks and personnel radioactive dose in nuclear power plants. Therefore, we conclude that the performance and reliability improvements and refinement of fossil fuel and nuclear power plants could be achieved by adoption of the new valve.



(a) Conventional valve seat **(b) New valve seat**

Fig. 4—Scanning Electron Micrographs of the Valve-seat Surfaces after Hot Water Erosion Test.
Results of the errosion test show that erosion damage sustained by the new valve seat is found to be 1/10 or less than that of the conventional valve seat.

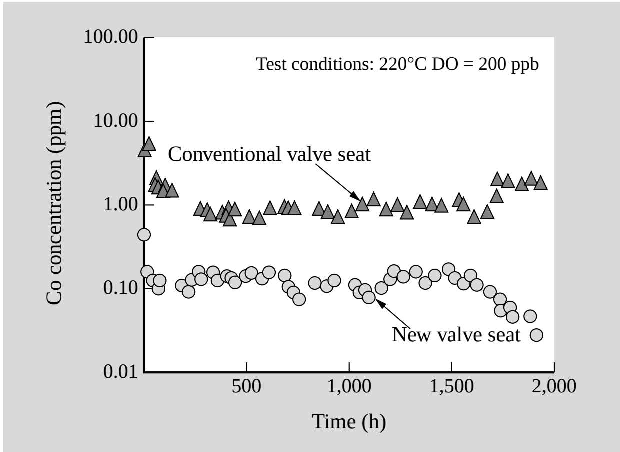


Fig. 5—Co Release Characteristics of Conventional and New Valve seats.
Results of the Co release characteristics test show that the amount of Co released by the new valve is 1/10 or less than that of the conventional valve.

(a) Conventional valve seat **(b) New valve seat**

Fig. 6—Appearance of Conventional (a) and New (b) Valve Seats Exposed to Actual Operating Plant Environment.
Results of practical test confirm the outstanding ability of the new valve to withstand corrosion and erosion compared with conventional valves.

Verification within Actual Operating Plant

To demonstrate the excellent qualities of the new valve in an actual operating plant, tests of both the conventional valve and the new valve were performed within the same operating plant for around one year. When exposed to the same environmental conditions, the conventional valve seat sustained considerable degradation. The result of the comparative evaluation of both valves is shown in Fig. 6. As the result of practical tests, the outstanding ability of the new valve to withstand corrosion and erosion compared with conventional valves was verified.

CONCLUSIONS

Compared to conventional valves, the new valve displays excellent performance in terms of all qualities required for such valves, meaning its adoption could meet many of the outstanding objectives not met by the use of conventional valves. Through subsequent valve performance improvements, the reliability and refinement of the fossil fuel and nuclear power plants could be improved. In the case of nuclear power plants, in addition to the reduced Co release, the annual radioactive dose sustained by personnel over many years could be decreased.

Moreover, the valve seat qualities that the concept and development of the new valve represents can meet requirements for corrosion and erosion control for various widely used corrosion- and wear-proof alloys under high temperature and corrosive conditions. From now, expansion of applications of the new valve will be a target.

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