Development of a New 12%Cr Steel Casting Utilizing USC Thermal Power Plant

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-Synopsis-

Improved 12%Cr steel casting which is used in the thermal power plant with elevating steam conditions for reducing CO_2-emission and saving our resources, was developed. Now, new 12%Cr steel casting which has better creep rupture strength than improved 12%Cr with adding to W, Co and B, is being studied. This paper describes mechanical properties, productivity, weldabilily and excellent creep rupture strength of these improved 12%Cr and new 12%Cr steel castings investigated by fundamental investigation and experimental manufacturing of the trial model casing.

1. Introduction

Recently, global environmental problems, in particular, the global warming have been discussed in a worldwide scale. The global warming is caused by several gases emission, and as their typical example, CO_2 should be taken up. CO_2 sources include thermal power plant in addition to household, factories, motor vehicles and so on. The reduction of CO_2-emission, therefore, has been one of the most important problems to be solved in thermal power plant[1-3].

In order to reduce CO_2-emission and saving energies, it is necessary to improve the thermal efficiency, for example, enlarging capacity of thermal power plant, elevating both temperature and pressure of steam conditions and converting into a combined cycle operation system[4-6]. From the point of view of an increase in steam temperatures and pressures, some thermal power plants have already started the operation under the steam conditions of 31.0MPa, 566/566/566℃ (main steam pressure and main steam temperature/1st reheating temperature/2nd reheating temperature) and of 24.1MPa, 566/593℃ (main steam pressure and main steam temperature/reheating temperature). Their turbine components, such as turbine rotor, casing, valve and the like, are required to have an excellent property at high temperature. Therefore, 12Cr materials have been being developed and applied.

Large-sized 12Cr steel casting products such as turbine casing and valve casing[7,8] were employed in the Kawagoe Thermal Power Plant, Chubu Electric Power Co., which started operating in 1989. Subsequently, they have been employed in several other thermal power plants. On the long term R&D programs, conventional 12Cr-Mo-V-Nb-N steel, improved 12Cr steel (containing W)[9-15] and new 12Cr steel (containing W, Co and B) have been studied and developed[16,17]. Actual products made of the improved 12Cr steel have been already manufactured and applied. In the new 12Cr steel, the trial model casing has been manufactured and evaluated, and the favorable results were obtained. In the near future, new 12Cr steel products will be employed in actual plants.

This paper mainly describes the development of improved 12Cr cast steel, which was developed to satisfy the requirements of high temperature properties[18]. In addition, new 12Cr cast steel whose development is now in progress is reported.

2. Development of Improved 12Cr Cast Steel

In order to develop the improved 12Cr cast steel, the fundamental investigation was performed to investigate the effects of Si, Ni, W and Ti, based on the chemical composition of conventional 12Cr cast steel. After determining its optimum chemical composition, trial model casing was manufactured and evaluated in various viewpoints of producibility and material properties.

2.1 Fundamental Investigation

2.1.1 Experimental Procedure

In the fundamental investigation, 50kg test materials were melted by the vacuum induction furnace and poured into the sand mold. These materials were composed of conventional 12Cr cast steel (No.1), and the effects of Si, W, Ni and Ti on material properties were investigated. One of the purpose of adding Ti

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Table 1 Chemical composition of test materials (mass%)

No.	C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb	N	W	Ti	Creq
No.1	0.15	0.24	0.62	0.004	0.002	0.50	10.0	0.87	0.23	0.10	0.04	…	…	7.60
No.2	0.15	0.07	0.62	0.004	0.002	0.51	10.1	0.90	0.23	0.10	0.04	…	…	6.60
No.3	0.12	0.07	0.62	0.005	0.003	0.51	10.2	0.94	0.23	0.09	0.05	0.96	…	9.27
No.4	0.12	0.07	0.62	0.004	0.003	1.01	10.1	0.92	0.22	0.11	0.04	0.98	…	7.23
No.5	0.13	0.08	0.62	0.004	0.002	1.54	10.2	0.93	0.23	0.10	0.04	1.00	…	5.11
No.6	0.12	0.07	0.62	0.004	0.002	1.02	10.1	0.91	0.23	0.10	0.04	0.48	…	6.58
No.7	0.12	0.07	0.62	0.004	0.002	1.01	10.0	0.89	0.23	0.10	0.04	1.51	…	8.10
No.8	0.11	0.07	0.63	0.004	0.002	1.02	10.2	0.92	0.23	0.11	0.04	1.07	0.02	8.12

included an estimation of the deoxidant as a substitute for Si. **Table 1** shows the chemical composition of these test materials.

The heat treatment shown in **Table 2** was carried out, which simulated the actual production steps. For normalizing, forced air-cooling was performed products. Since the test material was far smaller than the actual product, however, it was cooled in the open air. After the heat treatment, test pieces were taken in order to carry out various mechanical tests. The tensile property was tested at the room temperature with a JIS No.4 test piece (ϕ14mm, 50mmG.L.). The Charpy impact property was tested in a temperature range of −60℃ to 140℃ with a JIS No.4 test piece (2mm V-notched) to determine the FATT. The creep rupture property was tested at 630, 650 and 660℃ with single type and multiple type creep testing machines. Microstructure etched by 15% hydrochloric acid +1% picric acid alcohol solution was observed by optical microscope. Moreover, the carbide precipitating condition in the several specimens was observed by transmission electron microscopy(TEM) using carbon extracted replicas.

2.1.2 Results of fundamental investigation

Fig. 1 shows the tensile strength and elongation as a function of the content of each alloying element. A decrease of Si content led to a slight decrease in the tensile strength and an increase in elongation. An addition of W increased the tensile strength with

Table 2 Heat treatment condition of test materials

Heat treatment	Condition
Annealing	1070℃ ×20hr F.C.
Normalizing	1050℃ ×10hr A.C.
1st Tempering	570℃ × 8hr A.C.
2nd Tempering	705℃ ×16hr F.C.

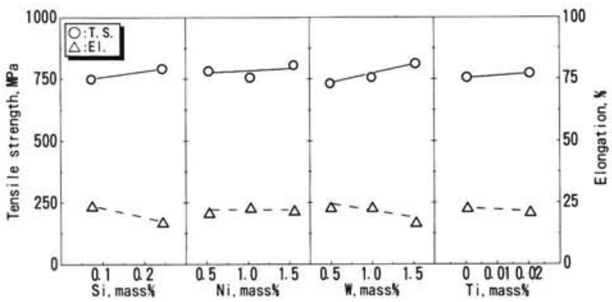


Fig. 1 Effects of Si, Ni, W and Ti on tensile properties

decreasing the elongation. Ni and Ti affected slightly on the tensile properties.

Fig. 2 shows the impact value at 20℃ and the FATT in Charpy impact test as a function of the content of each alloying element. A decrease of Si content led to improve impact value and the FATT. An increase of Ni resulted similarly. An addition of W decreased the impact value and degraded the FATT. Same result was obtained by adding Ti.

Fig. 3 shows the result of the creep rupture test. Test results were arranged by using the Larson-Miller parameter (L.M.P.) shown in equation (1), and the 10^5 hours creep rupture strength was obtained.

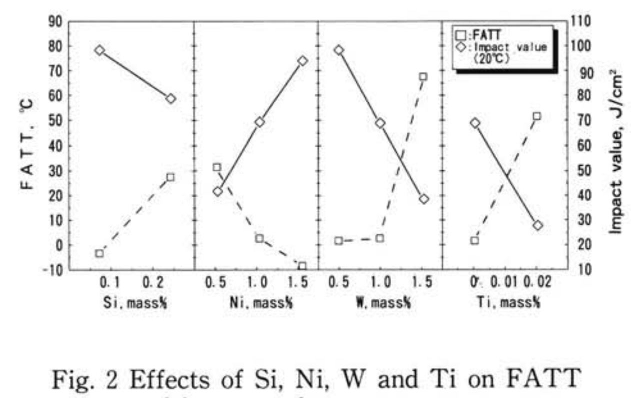


Fig. 2 Effects of Si, Ni, W and Ti on FATT and impact value

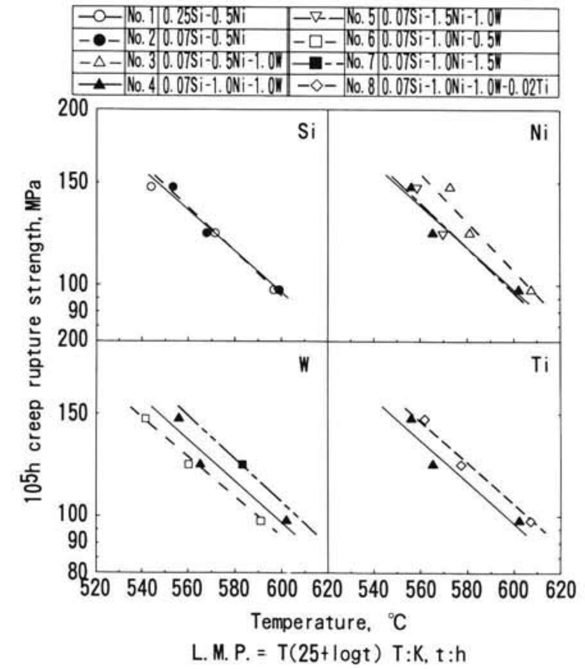


Fig. 3 Results of creep rupture test

L.M.P. = T (25 + log t),

T; K, t; h ....(1)

A decrease of Si content has no significant effects on the creep rupture strength. An increase of Ni content decreased the creep rupture strength, but its effects turned smaller at a content more than 1%. An addition of W improved the creep rupture strength. And according as the W content was increased, the creep rupture strength increased, too. An addition of Ti also improved the creep rupture strength similarly to the case of W.

Photo. 1 shows the microstructure of each material. The tempered martensitic microstructure was observed in all the materials. Delta-ferrite was found in the Nos.3 and 7, both relatively high Cr equivalents, and No.8 to which Ti had been added. Moreover, the inclusion, which was considered as TiN, was observed in No.8.

Concerning the relationship between delta-ferrite and notch-toughness in the 12Cr cast steel, it has been reported[19] that the existence of delta-ferrite decreased the impact properties because carbide coagulating and coarsening around the delta-ferrite supplies the sites where cracks initiate easily. Therefore, it is considered that delta-ferrite is one of the causes to degrade impact properties, coupled with the effects of the chemical composition.

Delta-ferrite is generally said to have a good correlation with the Cr equivalent. In addition, a few percent containing is allowed as required. To calculate the Cr equivalent, the equation of Schaeffler, Rickett and others have been proposed. In the 12Cr

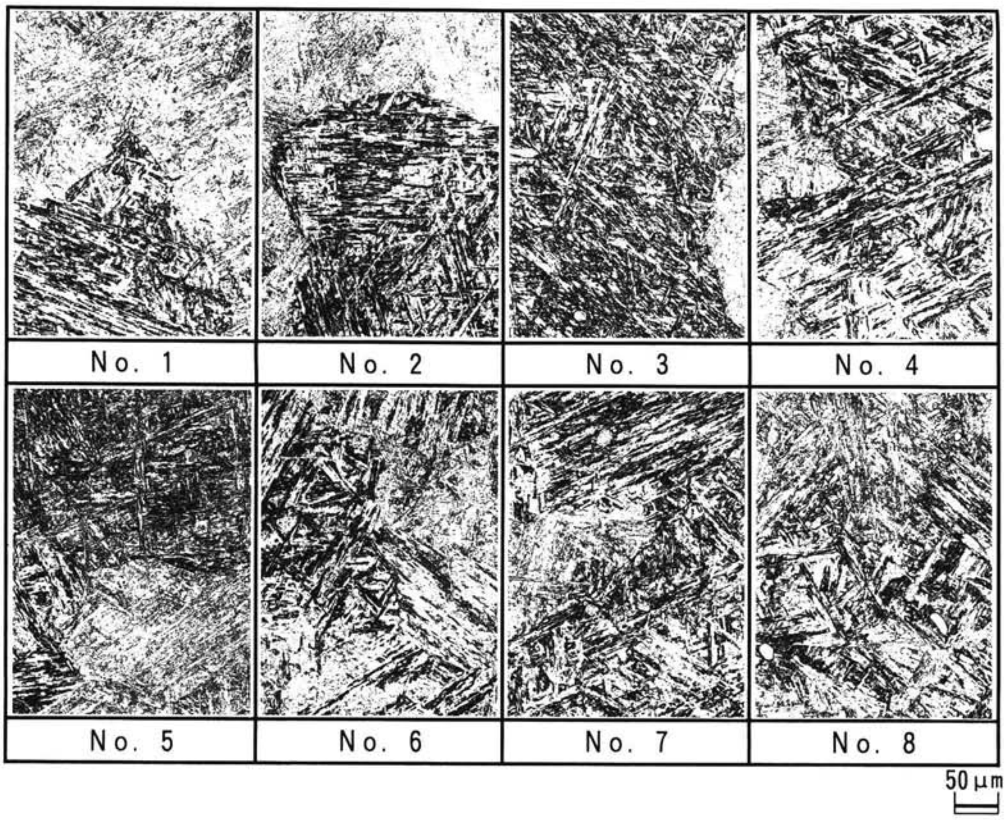


Photo. 1 Typical microstructures of test materials

steel, equation of Newhouse shown in equation (2) has been used in many cases[20].

$$\text{Cr equivalent} = Cr + 6Si + 4Mo + 1.5W + 11V + 5Nb + 8Ti - (40C + 2Mn + 4Ni + 2Co + 30N) \cdots\cdots (2)$$

Fig. 4 shows the relationship between the Cr equivalent calculated by equation (2) and the area ratio of delta-ferrite observed in each material. The area ratio of delta-ferrite was determined in accordance with JIS G0555. The existence of delta-ferrite can be discriminated by the critical Cr equivalent of 7.6. With the Cr equivalent higher than 7.6, delta-ferrite was observed. Between the area ratio of delta-ferrite and the Cr equivalent, however, we could not find out so favorable correlation. In this respect, it is necessary to investigate further in the future because of concerning with design of chemical composition, which also concerns with mechanical properties.

Photo. 2 shows the precipitated carbide morphologies of Nos. 2, 3, 4, 6 and 8, which were investigated with using a carbon extracted replica. It can be seen that carbides precipitate at the grain boundary and martensitic lath interfaces. The effects of the chemical composition on the precipitation of carbides could not be clearly confirmed.

Fig. 5 shows the EDS analysis of the typical carbides in Nos. 2, 3 and 8. The composition of the precipitating carbide in No.2 was Fe, Cr, Mo, V and Nb, and the carbide in No.3 contained same elements and W. In the carbides of No.8, Ti was not detected though Ti was added. Although the reason has been not clear, it is predicted that the amount of Ti about 0.02% was too small and fine TiC and TiN has precipitated independently.

The effects of W and Ti on the creep rupture

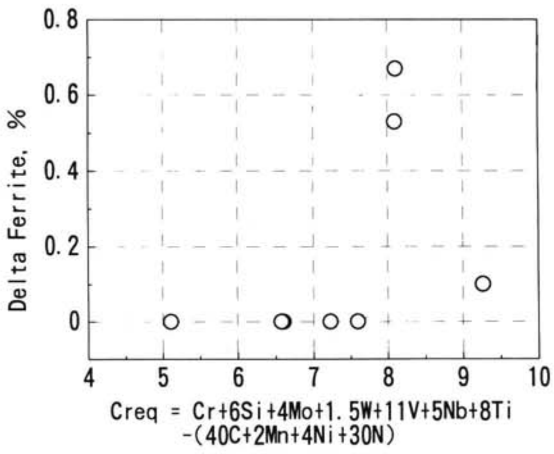


Fig. 4 Relationship between area ratio of delta-ferrite and Cr equivalent

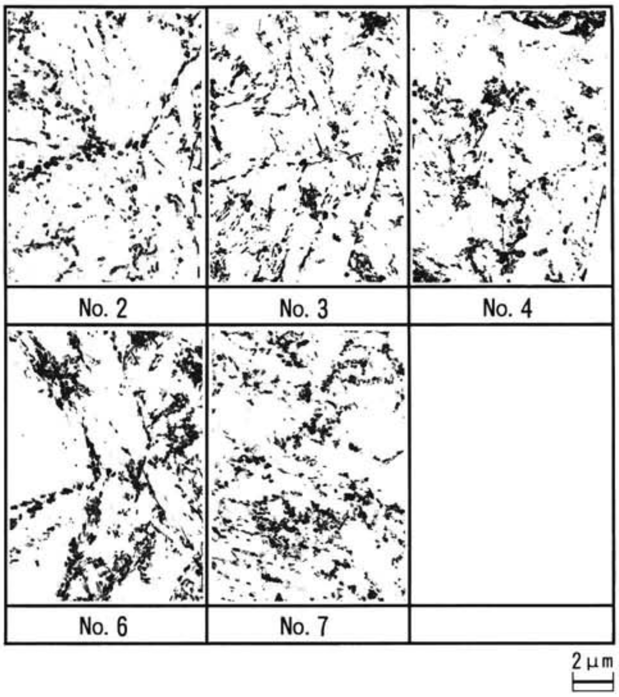


Photo. 2 Transmission electron micrographs of carbon extracted replicas

strength were studied by Liu et al[11,12]. The strengthening mechanism of W was mainly solution strengthening into the matrix and precipitation strengthening with carbides. In the precipitation strengthening proc-

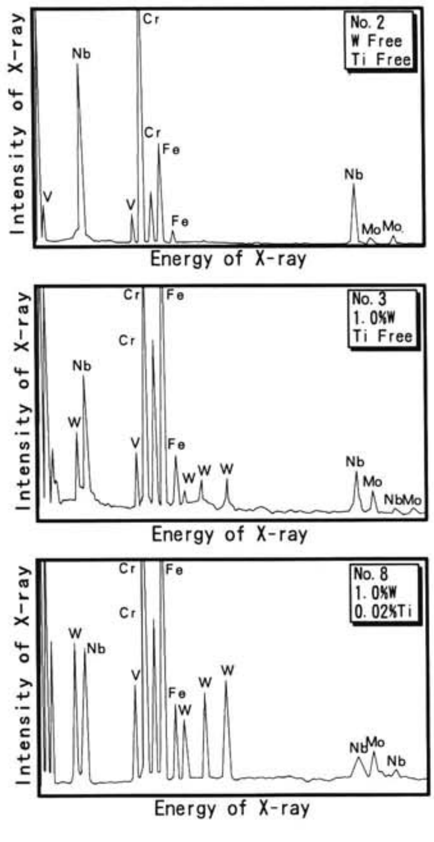


Fig. 5 Results of EDS analysis of typical carbide

ess, no W carbides formed independently, but $M_{23}C_6$ or M_6C containing W was formed. Moreover, W would increase the high temperature stability of carbides and suppress coagulating and coarsening of carbides.

For the effects of Ti, they described that Ti was a strong carbide-forming element and formed MC type carbide by itself. Moreover, fine (Ti,Nb)(C,N) was formed by the combined addition of Ti and Nb, and they prevented the moving of dislocation. It is considered that the creep rupture strength improved with above factors.

2.2 Manufacturing of Trial Model Casing

Actual products, such as turbine casing, are very thick and maximum wall thickness is from 400 to 500 mm. In addition, they have the complicated shape and various wall thickness. In the manufacturing of the turbine casing, therefore, it is necessary to plan an optimum casting design not to form several casting defects such as shrinkage cavity and the like. Coupled with this, it is necessary to consider the heat control with respect to cutting off the risers, shaping using air arc gouging and the weldability concerned with structural welding and repair welding. Based on the fundamental investigation, the optimum chemical composition was determined and the trial model casing was manufactured to investigate the mechanical properties, weldability, producibility and internal qualities. Moreover, the detail of heat treatment conditions for the trial model casing was determined using the large-sized test material which was produced together with the trial model casing. **Photo. 3** shows the appearance of the trial model casing weighed about 9 tons.

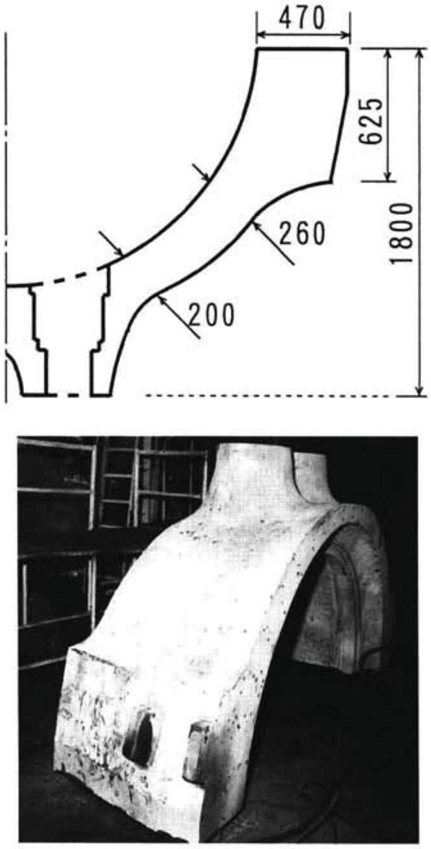


Photo. 3 External view of model casing

2.2.1 Optimization of Chemical Composition

Based on the fundamental investigation, it was determined that W content, which was characteristic of improved 12Cr cast steel, was 0.9%, considering that the creep rupture strength might be improved though it would degrade the impact properties. In addition, an increase of the Cr equivalent was suppressed by decreasing Si, increasing Ni and adjusting other compositions, to prevent a remaining of delta-ferrite. The addition of Ti to the developed material should not be carried out, because the addition of Ti would surely improve the creep rupture strength while probably degrading the impact properties due to remaining delta-ferrite. Therefore, Si was required as a deoxidant and was added within a range of 0.05 to 0.15%. **Table 3** shows the determined chemical composition of the trial model casing, compared to conventional 12Cr steel casting.

2.2.2 Optimization of Heat Treatment Conditions

In order to investigate the effect of normalizing temperature on both the creep rupture strength and the tensile strength, and to optimize the heat treatment conditions of the trial model casing, the large-sized test material weighed about 1.2 tons, which was produced with the trial model casing, was prepared. The conventional 12Cr cast steel had been usually

Table 3 Chemical composition of model casing (mass%)

	C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb	N*	W	Remark
Conventional 12Cr cast steel	0.14	0.28	0.57	0.007	0.006	0.52	10.10	0.88	0.22	0.10	382	…	product
Improved 12Cr cast steel	0.12	0.09	0.60	0.007	0.003	0.80	9.69	0.80	0.20	0.09	487	0.90	model casing

(* : ppm)

normalized at 1050℃. Yamada et al.[21,22], however, reported that the creep rupture strength was improved with higher austenitizing temperature. The effect of normalizing temperature on creep rupture strength was investigated using the two materials normalized at 1050℃ and 1070℃, respectively.

The 2nd tempering temperature had a significant effect on the tensile strength. The test materials were heat treated in a temperature range of 700 to 750℃ to investigate the relationship between the tensile strength and the 2nd tempering temperatures. Since increasing the normalizing temperature might possibly lead to a degradation of the impact properties, the Charpy impact test was also carried out.

2.2.3 Influence of Heat Treatment Conditions on Tensile Strength

Fig. 6 shows the tensile strength and the FATT as a function of the 2nd tempering temperature. The tensile strength decreased and the FATT improved conversely with increasing 2nd tempering temperature. The effect of the normalizing temperature was insignificant to the tensile strength and impact toughness. It is necessary that the tensile strength should aim from 750 to 800MPa in order to maintain both strength and toughness. As the another reason, it is necessary to decrease the difference of tensile strength between turbine casing and pipes, which are welded structurally and have lower strength than turbine casing. From these results, the 2nd tempering temperature was determined to be 710℃.

2.2.4 Influence of Normalizing Temperature on Creep Rupture Strength

Fig. 7 shows the relationship between the normalizing temperature and the creep rupture strength in the condition of 2nd tempering temperature at 710℃. From this figure, a higher normalizing temperature increased slightly the creep rupture strength. It is considered that there are two factors, which improve the creep rupture strength with increasing the normalizing temperature.

These are as follows; (1) An increase in the amount of carbides solution, and (2) Growth of grains. As a result of microstructural observation, it was found that there was no significant difference in both microstructure and grain size. Therefore, it is considered that the cause of (1) is significant. From these results, the normalizing temperature was determined to be 1,070℃.

2.3 Producibility and Mechanical Properties of Trial Model Casing

2.3.1 Effect of Air Arc Gouging

Large-sized cast steel products, such as a turbine casing, are necessary for many hours to finish solidification, so that several casting defects such as shrinkage cavity may be formed easily. Consequently, adequate risers and padding design were important to maintain the internal quality. These risers and padding are generally removed by flame cutting or air arc gouging. At this time, it is possible to form cracks by coarsening carbides, which have precipitated during the solidification and flask cooling in the

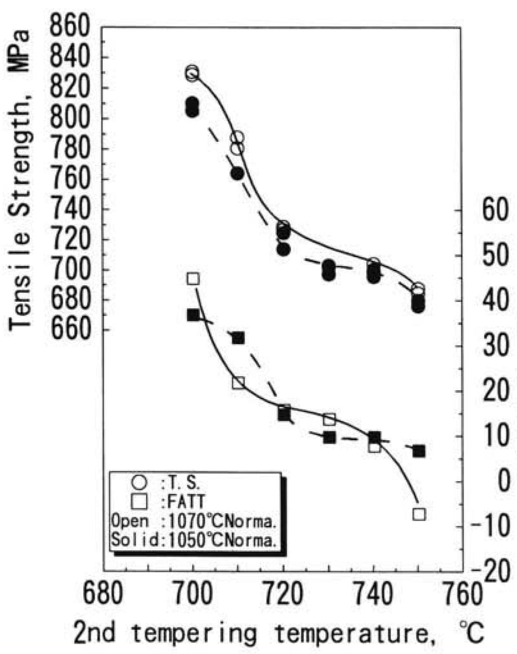


Fig. 6 Effect of normalizing and 2nd tempering temperature on tensile strength and FATT

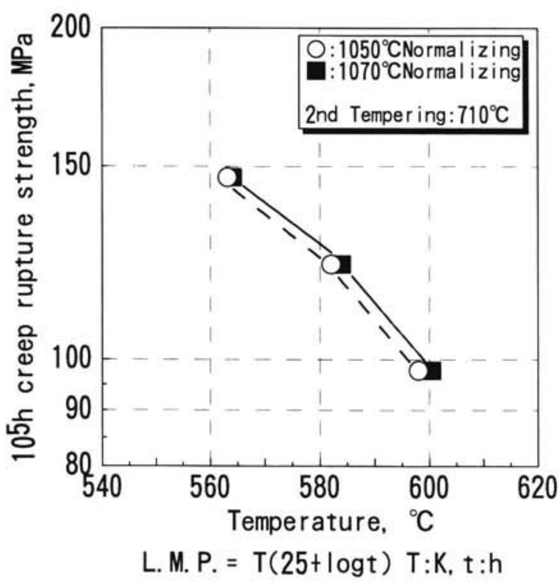
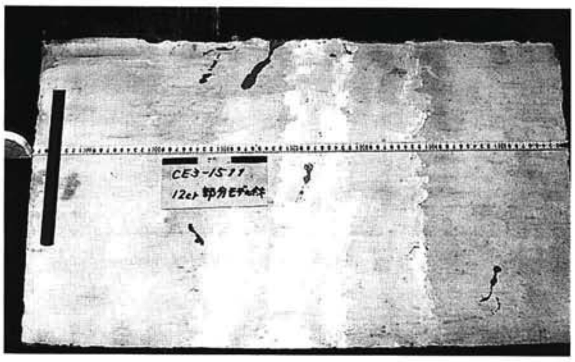
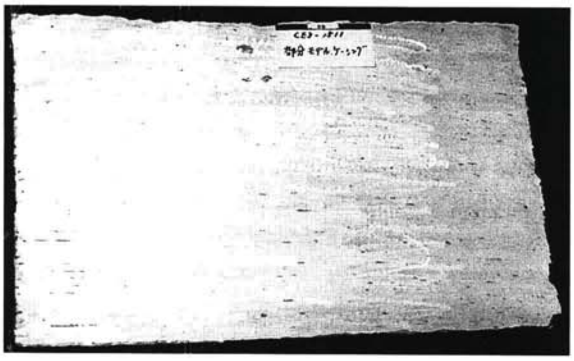


Fig. 7 Effects of normalizing temperature on 10^5 hours creep rupture strength



As cast (small cracks observed)



After annealing (no crack)

Photo. 4 Crack susceptibility caused by air arc gouging

sand mold. It is necessary, therefore, to investigate the effects of air arc gouging to remove risers and padding. **Photo. 4** shows the results of investigation on the crack susceptibility of air arc gouging comparing with as-cast and after annealing at 1070℃ by means of liquid penetrant testing(PT). The large-sized test material manufactured with trial model casing was used in this investigation. The as-cast material had some cracks generated on the surface while the annealed material did not have any cracks. It may be judged that annealing at 1,070℃ improved the structure through the solution of harmful coarsen carbides and crack susceptibility decreased.

2.3.2 Segregation of Chemical Compositions

In case of taking for many hours to finish the solidification, the segregation of chemical composition was formed generally in the product. Especially just below the riser, such elements as C, Cr, P and S have a tendency to concentrate. **Fig. 8** shows the chemical composition (C, Cr, S and W) at different position on the cross section of the trial model casing. There was no difference in terms of the chemical composition in all positions. At the center of the top of the horizontal flange, just below the riser, C concentration was detected slightly. From this investigation, It was confirmed that the chemical composition was successfully uniform.

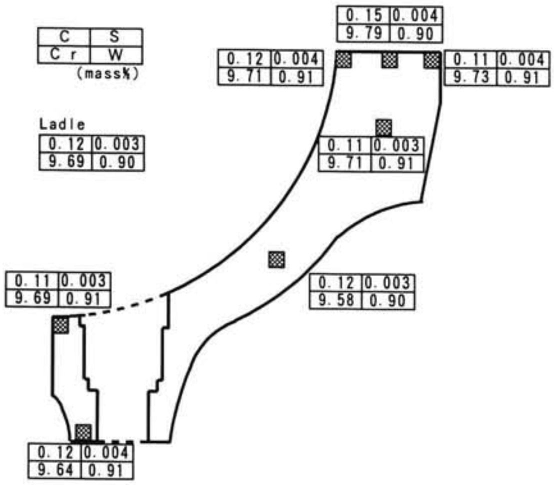


Fig. 8 Results of C, S, Cr and W analysis in model casing

2.3.3 Solidification Property

A product is inspected for its internal quality through such nondestructive testing as ultrasonic testing and radiographic test. It is necessary, therefore, to grasp the problems with respect to the influence of solidification and/or segregation over the internal quality. **Photo. 5** shows the results of sulfur print (SP), PT and macrostructure on the cross section of the trial model casing. SP-indications could be observed slightly only at the thick-wall portion. As the result of PT, several PT-indications were found at the position where the SP-indications were located. In the macrostructure, it was observed slightly to form A-segregation. The location of SP/PT-indications corresponds to form the casting defect accompanying the A-segregation. Such an A-segregation is well known to take place at the thick-wall portion. Especially in case of a large-sized steel casting, such segregation is a normal phenomenon[23). In this investigation, no abnormality in relation to solidification could be observed.

2.3.4 Weldability

It is ideal to make a defect-free product for casting. It is very difficult, however, to do so in making a large-sized cast product. Generally, therefore, repair welding is applied to those defects beyond the allowable size. Moreover, structural welding with short pipe and flange elbows is carried out. Consequently, weldability becomes one of the critical material requirements. **Fig. 9** shows the relationship

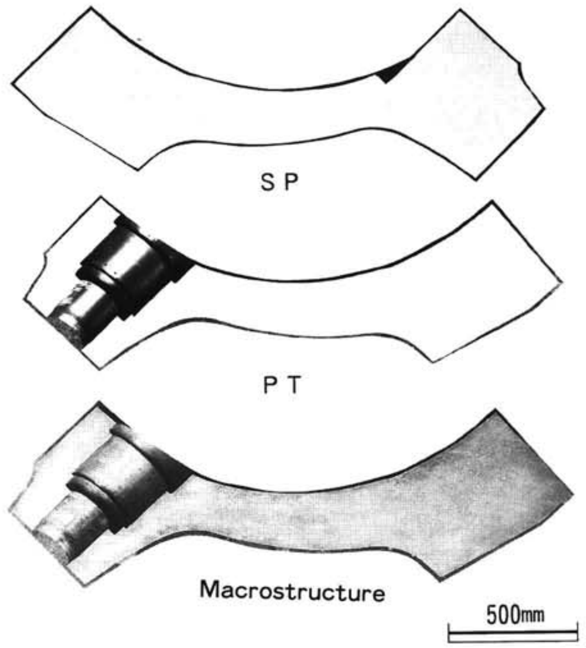


Photo. 5 SP, PT and macrostructure of vertical section of model casing

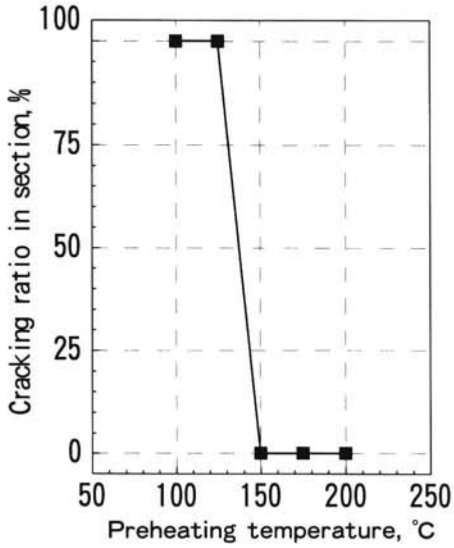


Fig. 9 Result of y-groove weld cracking test

between preheating temperature and the cracking ratio in the y-groove weld cracking test. Crack formation was found below 125℃. With industrial safety margin taken into consideration, a preheating temperature was desirable more than 200℃, which is the equal level with that of the conventional 12Cr cast steel. From these results, it could be confirmed that the trial model casing indicated sufficient weldability.

2.3.5 Mechanical Properties and Microstructure

As compared with a small test material, the cooling rate of the large-sized test material is very slow during solidification and normalizing process. These phenomena appear to exhibit mass effects, such as degrading the mechanical properties, especially in the ductility and the toughness, at the center of thick-wall portion. **Fig. 10** shows the tensile strength, elongation, impact value, FATT and the amount of delta-ferrite in various location of the trial model casing. There was no difference in the tensile strength. Significant differences in the elongation could not be observed although degraded slightly at the center (B and D). Both the impact value and the FATT also could not found to differ significantly similarly to the tensile strength. Delta-ferrite was slightly observed at the center of the thick wall portion. Moreover, it was observed at other locations except for the test coupon (A) attached to the hori-

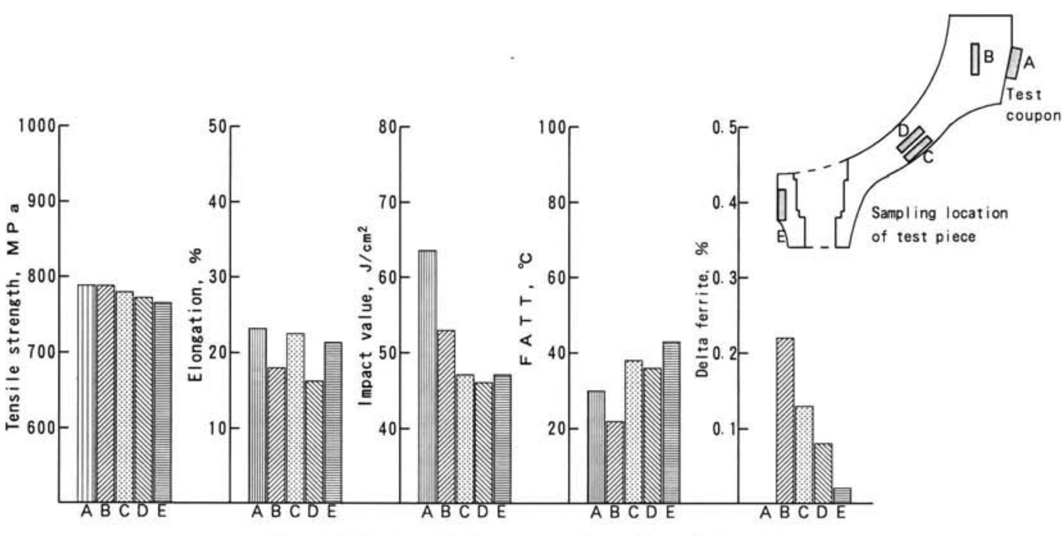


Fig. 10 Mechanical properties of model casing

zontal flange. It was thought that delta-ferrite remained comparative easily because solidification rate of the trial model casing was very slow compared with the small test material used fundamental investigation. However, there was minor effect on the mechanical property because its area ratio was equal level of inclusion. From these results, it can be seen the developed material has small mass effects.

2.3.6 Creep Rupture Strength

Fig. 11 shows the results of the creep rupture test on the trial model casing, including the test results on the conventional 12Cr cast steel for the purpose of comparison. The test pieces were sampled at B, C and D in Fig. 10. Comparing with each creep rupture strength at a temperature of 593℃, the conventional 12Cr cast steel had a mean value of about 90MPa while the developed material showed about 105MPa. It can be seen a 15% improvement of creep rupture strength. No effect of the delta-ferrite could be confirmed according to a difference in sampling location.

As a result of manufacturing of the trial model casing which has a size equivalent to the actual product, it was confirmed that the mechanical properties were as same as the results of fundamental investigation and producibility was equal level to the conventional 12Cr cast steel.

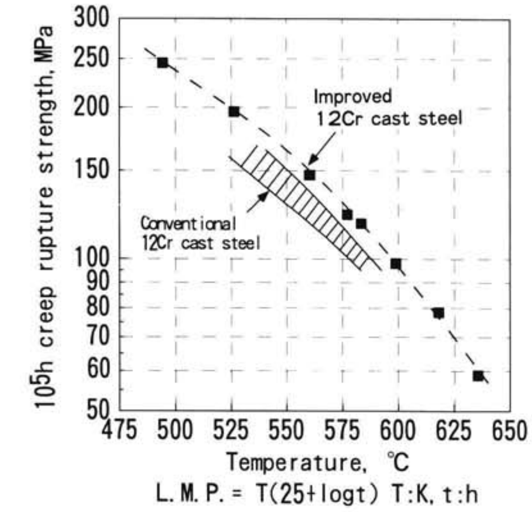


Fig. 11 Comparison creep rupture strength between conventional and improved 12Cr cast steel

3. Development of New 12Cr Cast Steel

The new 12Cr cast steel is now under development as the steam turbine component for ultra super critical pressure thermal power plant whose steam temperature may rise up to 630℃ at the maximum. In order to improve the creep rupture strength, W content was increased, and B and Co were added to the improved 12Cr cast steel. The purpose of an addition of Co is to suppress an increase of Cr equivalent accompanying an increase of W content. For the new 12Cr forged steel material, test manufacturing of a actual product size model was carried out and was verified above mentioned effect of each element. The present paper reports the effect of B on mechanical properties and weldability.

3.1 Test Method and Results

In this study, 50kg test materials were used similarly to the fundamental investigation on the improved 12Cr cast steel. **Table 4** shows the chemical composition of the materials together with that of the trial model casing referred to later. Test materials Nos. 9 and 10 were intended to investigate the effects of an addition of B on the mechanical properties and the creep rupture strength. Each material was subjected to the mechanical test and to the creep rupture test after heat-treated under the conditions shown in **Table 5**. Material Nos. 11 through 14 were intended to investigate the effects of B and Ti on weldability, with the B content made to vary from 40 through 120 ppm. Nos. 13 and 14 had Ti added at 0.03% for the purpose of fixing N. These materials were welded one layer three passes with shielded metal arc welding onto the 30mm thick plate which

Table 4 Chemical composition of test materials and model casing used to develop new 12Cr cast steel (mass%)

No.	C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb	N*	W	Co	B*	Ti	Remark
No.9	0.12	0.17	0.52	0.006	0.002	0.22	10.3	0.66	0.20	0.06	195	1.71	3.05	···	···	Used for mechanical test
No.10	0.13	0.16	0.53	0.006	0.003	0.22	10.1	0.66	0.20	0.06	196	1.77	3.06	50	···	
No.11	0.12	0.16	0.53	0.009	0.002	0.22	10.3	0.65	0.21	0.05	233	1.80	3.17	40	···	Used for weldability test
No.12	0.12	0.15	0.53	0.009	0.002	0.22	10.1	0.65	0.21	0.05	273	1.80	3.15	80	···	
No.13	0.13	0.16	0.54	0.010	0.002	0.22	10.1	0.65	0.21	0.06	250	1.78	3.11	90	0.03	
No.14	0.12	0.17	0.55	0.009	0.002	0.22	10.2	0.66	0.21	0.06	244	1.78	3.10	120	0.03	
Model	0.14	0.20	0.49	0.008	0.002	0.20	10.0	0.63	0.21	0.05	243	1.70	2.95	80	···	

(*)ppm)

Table 5 Heat teatment conditions of test materials used to develop new 12Cr cast steel

Heat treatment	Condition
Annealing	1070℃ ×20hr F.C.
Normalizing	1070℃ ×10hr A.C.
1st Tempering	570℃ × 8hr A.C.
2nd Tempering	740℃ ×16hr F.C.

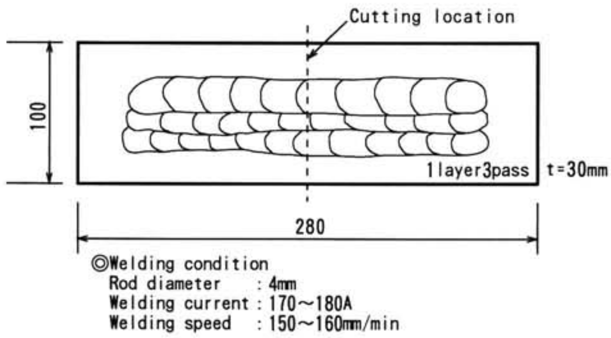


Fig. 12 The outline of weldability test

had already annealed at 1,070℃ for 20 hours. On the cross section vertical to the direction of weld beads, the microstructure was observed to check crack formations. **Fig. 12** shows the outline of the welding test.

Fig. 13 shows the results of the mechanical test on the Test Materials Nos. 9 and 10. Comparing these materials, the tensile strength of the material containing B is higher about 50MPa than the material without B in spite of same heat treatment. It can be seen that the temper resistance was improved by an addition of B. **Fig. 14** shows the results of the creep rupture test, together with the test results on the trial model casing referred to later. Comparing the 10^5 hours creep rupture strength at 600℃, the B free material indicated 105MPa and the B containing material indicated 125MPa. Thus, an addition of B dramatically improved the creep rupture strength.

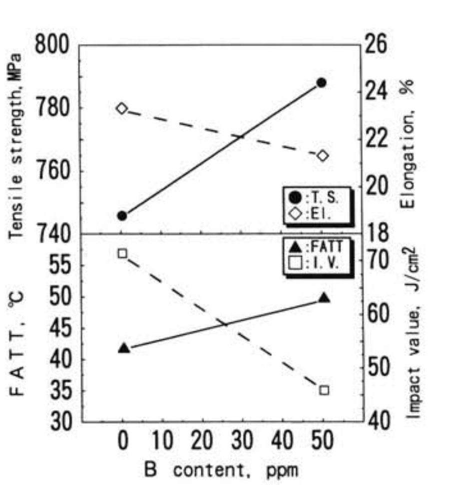


Fig. 13 Effect of B content on mechanical properties of new 12Cr cast steel

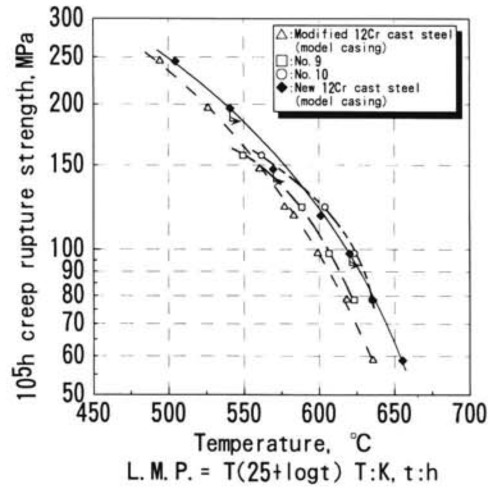


Fig. 14 Result of creep rupture test on new 12Cr cast steel

Photo. 6 shows the microstructure around fusion line in the materials Nos.11 through 14. Nos.11, 12 and 13 did not have any defects, such as cracks, on the observed surface. No.14, however, had a crack-like defect observed. These cracks were observed along the grain boundary of HAZ near the fusion line. It may be considered that the grain boundary embrittlement is occurred with adding B of 120ppm and

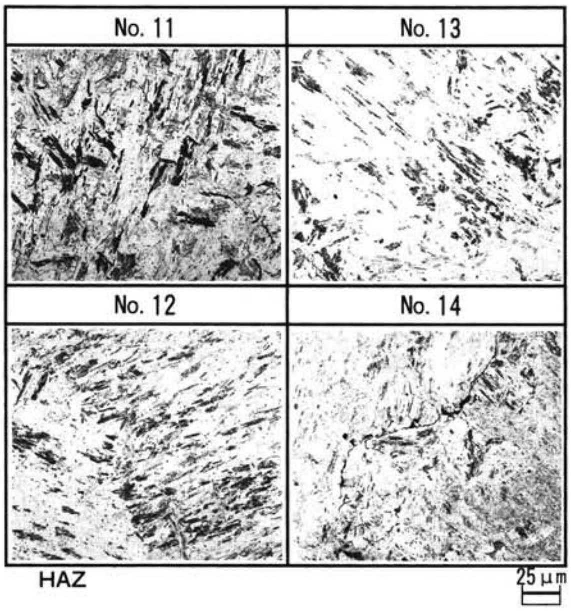


Photo. 6 Results of weldability test

cracks formed due to the thermal stress caused rapid heating and cooling in the welding process. From these results, the B content is required not to contain above 100ppm considered the weldability. No effect of 0.03% level Ti content on weldability was recognized.

3.2 Manufacturing of Trial Model Casing

Based on the fundamental investigation, the target chemical composition of new 12Cr cast steel was determined. In order to verify its producibility, the trial model casing of new 12Cr cast steel was manufactured and evaluated. The trial model casing was shaped identically with that of the improved 12Cr cast steel. The chemical composition of the trial model casing is shown in Table 4. As a result of evaluating, it was found at the level identical with the improved 12Cr cast steel in terms of producibility and internal quality. Besides, it was confirmed that the new 12Cr cast steel had uniform mechanical properties, too.

The result of the creep rupture test of the trial model casing is shown in Fig. 14. It was confirmed that the trial model casing possessed the creep rupture strength equal to that in the fundamental investigation. The improved 12Cr cast steel had the creep rupture strength of 98MPa at 600℃ while the new 12Cr cast steel showed about 125MPa. From this result, the new 12Cr cast steel has the creep rupture strength improved more than 25%.

Based on the results referred to above, it was confirmed that the new 12Cr cast steel was applicable to the large-sized product.

4. Conclusion

In order to improve the creep rupture strength of 12Cr cast steel used for thermal power plant with increasing steam temperatures and pressures, the fundamental investigation to determine the optimum chemical composition and manufacturing test using trial model casing to verify producibility of the developed material were carried out. Based on these test results, improved 12Cr cast steel containing W was developed. The results are summarized as follows;

(1) The fundamental investigation was conducted to investigate the effects of alloying elements on the mechanical properties of 12Cr cast steel. As a result, it was found that the alloying of W increased both tensile strength and creep rupture strength while decreased both the impact value and the FATT. Reducing Si and an addition of Ni improved impact value and the FATT while an addition of Ni decreased the creep rupture strength. And an addition of Ti improved the creep rupture strength while the impact value and the FATT were degraded due to precipitate delta-ferrite.

(2) As a result of studying relationship between the heat treatment conditions and the mechanical properties, it was confirmed that a higher normalizing temperature improved the creep rupture strength accompanying no effects on the impact properties.

(3) As the results of the manufacturing test to investigate the segregation of alloying elements, internal quality, weldability and mass effects on the mechanical properties, it was verified that improved 12Cr cast steel had desirable producibility at the level similar to the conventional 12Cr cast steel.

The improved 12Cr cast steel, moreover, had satisfactory creep rupture strength at a service temperature of 593℃ improved by about 15% comparing with the conventional 12Cr cast steel.

Concerning the new 12Cr cast steel now under development, the obtained results are summarized as follows;

(4) An addition of B improved the tempering resistance and dramatically increased the creep rupture strength.

(5) An addition more than 100ppm of B affected weldability adversely in shielded metal arc welding.

(6) As a result of manufacturing the trial model casing, it was confirmed that producibility of the B added steel equaled to the improved 12Cr cast steel and was applicable to a large-sized product. The creep rupture strength at 600℃ reached about 125MPa, showing an improvement by more than 25% as compared with the improved 12Cr cast steel.

5. Acknowledgement

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