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Effect of Vanadium on Subcritical Heat Treatment Behavior of Hypoeutectic 16 wt% Cr Cast Iron containing 2 wt% Mo

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Abstract

Subcritical heat treatment of austenite in alloyed cast iron by tempering at the temperature below pearlite transformation (A1), has been used to improve matrix hardness without hardening. Hypoeutectic high chromium cast irons containing 16 wt% Cr - 2 wt% Mo without and with V were prepared in order to clarify the effect of holding temperature and holding time on behavior of hardness and decomposition fraction of austenite in matrix (f) in subcritical heat treatment. As-cast specimens were held at temperature from 723 K to 923 K for 14.4 - 43.2 ks, and then cooled by fan air. In the as-cast state, macro-hardness and micro-hardness increased gradually with an increase in V content. The f increased with the raising V content. In subcritical heat treatment state, the hardness curves showed a secondary hardening due to precipitation of secondary carbides in matrix and transformation of destabilized austenite into martensite during cooling. The degree of secondary hardening was greater in the V-free specimen than that in the V-containing specimens. The f increased greatly when the holding temperature increased over 823 K. The maximum hardness in subcritical heat treatment (H_{STmax}) stage was obtained by treatment condition of 823 - 873 K for 14.4 - 43.2 ks where the f was about 60-80%. The macro-hardness curves showed similar behavior to the micro-hardness curves. The H_{STmax} increased gradually with an increase in V content. The largest H_{STmax} value of 848 HV30 was obtained in the 3 wt% V specimen. The highest abrasive wear resistance was obtained in the specimen with H_{STmax}.

Key words: Subcritical heat treatment, 16% Cr cast iron, Hardness, Abrasive wear resistance, V effect

Introduction

White cast iron has developed over a long period of time for many applications but mainly as abrasion wear resistant materials. High chromium cast iron, which contains chromium from 10-30 wt% (hereafter show by %), has found wide applications in various fields of industries. For example it has been used as raw materials of work rolls in steel industry, roller and table of pulverizing mills and components or parts in mining and cement industries because of its high abrasion wear resistance.

The purpose of Mo addition is to avoid formation of pearlite in as-cast condition and to improve hardenability during heat treatment. As can be expected, Mo tends to form its own carbides of Mo_2C or M_2C type with very high hardness.[1-3] Mo dissolved in austenite improves hardness by promoting the secondary precipitation of molybdenum carbides and also distributed into M_7C_3 carbide increasing hardness of carbide itself. It has been reported that the presence of M_2C carbides leads to improving abrasion wear resistance.[3] In case that higher hardness is necessary, V has been added to cast iron. This is because V is strong carbide former. It could form VC with extremely high hardness and refine carbide structure.[1,3] It was reported that V improved wear resistance of as-cast 16% Cr cast irons.[3]

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A large amount of retained austenite in as-cast condition promotes spalling which reduces the service life.[3] Since martensitic matrix improves hardness, abrasion wear resistance and resistance to spalling, cast iron need to be heat-treated. When medium hardness is required in high Cr cast iron, subcritical heat treatment, which is to hold the specimen at temperature lower than pearlite transformation point (A1), is applied to the as-cast iron.

Studies on improvement of solidification structure and matrix structure as well as systematic research on general heat treatment of hardening and tempering have been extensively reported(4-9). However, the research on subcritical heat treatment is quite limited.[10] In this study, therefore, hypoeutectic 16% Cr - 2%Mo cast iron with and without V were prepared, and effects of V content on behavior of hardness and decomposition fraction of austenite in subcritical heat treatment were investigated by varying holding temperature and holding time. In addition, the abrasive wear resistance of subcritically heat-treated specimens under suitable conditions was evaluated.

Materials and Experimental Procedure

Preparation of Specimen

Cast iron with the target composition was produced using a 30 kg-capacity high frequency induction furnace with alumina lining. Charge materials consisting of mild steel scrap, pig iron, ferroalloys and pure metals were melted and superheated up to 1853 K then poured at 1773-1793 K into preheated CO_2 mold Figure 1 with dimensions of ϕ25x65 mm with sufficient riser. After pouring, the melt was immediately covered with dry exothermic powder to prevent the riser from fast cooling. The chemical composition is illustrated in Table 1.

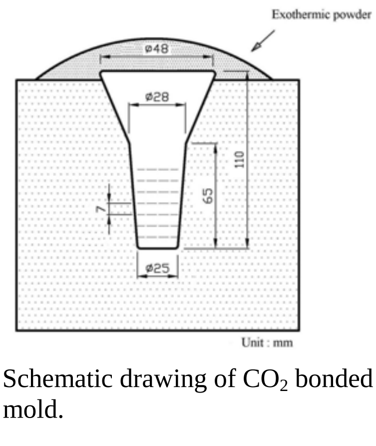


Figure 1. Schematic drawing of CO_2 bonded sand mold.

Specimen	Element (wt%)					
	C	Si	Mn	Cr	Mo	V
No.1	3.04	0.52	0.50	15.90	2.01	0.08
No.2	3.07	0.61	0.54	16.28	2.00	1.03
No.3	3.03	0.57	0.52	16.41	1.95	1.97
No.4	3.05	0.58	0.46	15.66	2.05	2.81

Table 1. Chemical composition of test specimens.

Heat Treatment Procedure

An as-cast specimen was heated up to subcritical temperatures at 50 K intervals from723 K to 923 K for 14.4 ks to 43.2 ks and then cooled to room temperature by fan air cooling.

Measurement of Hardness and Decomposition of Austenite

Macro-hardness of specimen was measured by means of a Vickers hardness tester employing the load of 300 N (30 kgf) and hardness of matrix was obtained by Micro-Vickers hardness tester applying the load of 1 N (0.1 kgf). More than five impressions were taken and measured values were averaged.

The microstructural examination of specimens was carried out by metallograhpy to discuss experimental results. To observe microstructures, specimens were polished using emery papers and then finished by a buff cloth with extremely fine alumina powder of 0.3 µm in diameter. The microstructures were revealed using Vilella’s reagent. Investigation was performed by an optical microscope (OM) and a scanning electron microscope (SEM). The decomposition fraction of austenite (f) was measured by image analysis. In each specimen, the images were carefully taken around the center of test piece and more than 50 fields at 200 times were adopted for calculation. The decomposition fraction of austenite (f) was calculated using the following equation;

$$f(\%)(\frac{Ad}{Am}x100)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(1)}$$

f = Decomposition fraction of austenite
Ad= Area fraction of transformation
Am = Area fraction of matrix

Abrasion Wear Test

A schematic drawing of an abrasion wear tester is illustrated in Figure 2. Under the load of 5 N (0.5 kgf), abrading wheel (44 mm in diameter and 12 mm in thickness) stuck a 180 mesh SiC abrasive paper on circumference was revolved intermittently while moving back and forth by 35 mm traveling stroke on the same area of test piece in dry condition. The revolving speed of abrading wheel was 0.345 mm/s and the worn area was 420 (12x35) mm^2. The abrasion wear loss of test piece was measured using an electronic balance after one cycle test, which takes 400 s, and the test was repeated up to eight times for one test piece.

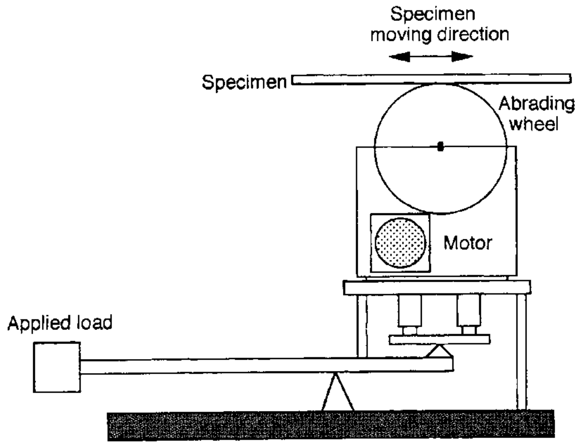


Figure 2. A schematic drawing of abrasion wear testing machine.

Results and Discussions

As-cast state

As-cast microstructures of the 16%Cr-2% Mo cast irons with and without V are representatively shown in Figure 3. In each specimen, microstructure consists of primary dendrites and eutectic structures. The morphology of (γ+M_7C_3) eutectic in specimens with V is smaller than that in the V-free specimen. It was also found that carbide size seems to decrease with an increase in V content. Matrix structures of all specimens are austenitic with small amount of martensite. It is clear that VC (MC type) carbides precipitate as primary carbide in the 3% V specimen, because V is a strong carbide former and form carbide by combining with carbon.

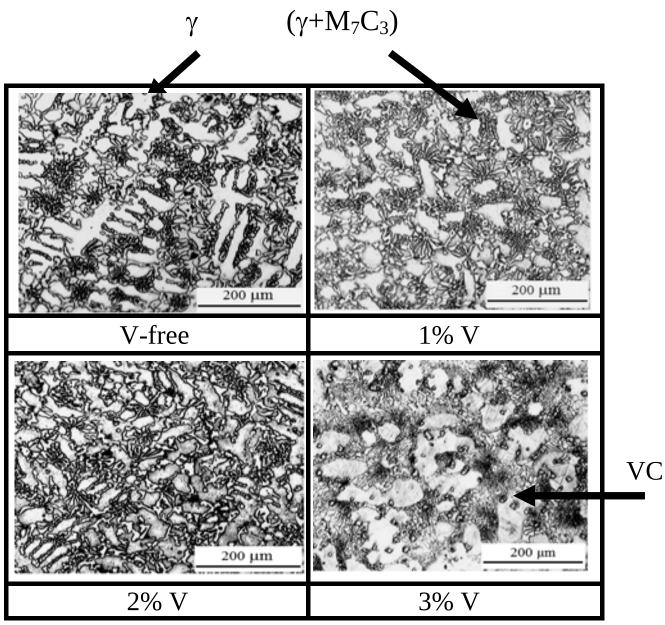


Figure 3. Microphotographs of as-cast hypoeutectic 16% Cr -2% Mo cast irons without and with V.

Effect of V content on hardness and decomposition fraction of austenite (f) in as-cast state is shown in Figure 4. The macro-hardness increases gradually with an increase in V content. The change in micro-hardness shows a similar behavior to that in macro-hardness. The f increases gradually as the V content increases. This is because V decreases carbon content in austenite and raises the martensite start temperature (Ms). Here, it can be concluded that an increase in amount of martensite with increasing V content resulted in high hardness.

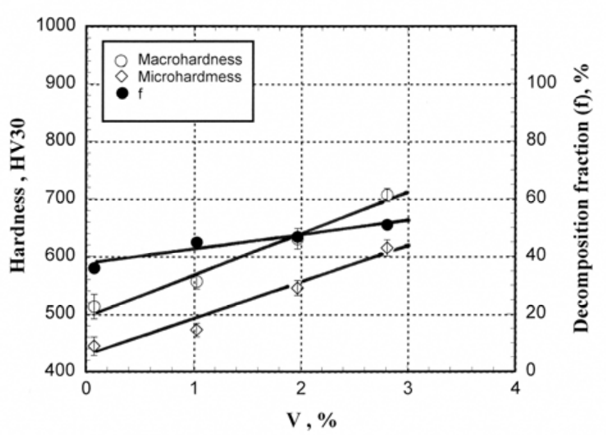


Figure 4. Effect of V content on hardness and decomposition fraction of austenite (f) of the 16% Cr-2% Mo cast irons in as-cast state.

Subcritical Heat Treatment State

As-cast specimens were heat-treated at temperatures from 723 to 923 K. As a typical example, the microstructure of the 3% V specimen held for 43.2 ks for various temperatures is shown in Figure 5. As holding time increases, the dark area where austenite transformed into martensite increases. This proves that decomposition of austenite proceeds isothermally with an increase in holding temperature.

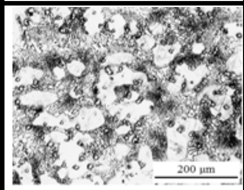
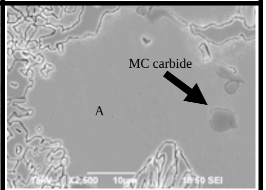
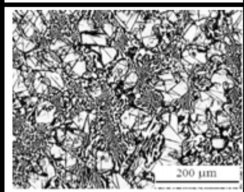
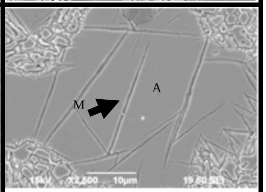
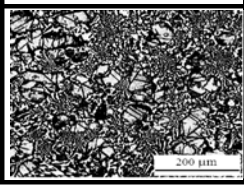
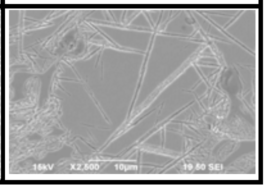
Specimen	OM	SEM
As-cast		
823 K		
873 K		

Figure 5. Phase transformation of subcritically heat-treated 3% V specimen. Holding time: 43.2ks (A:austenite,M: martensite)

Relationships between macro-hardness, f and holding temperature of test specimens are shown in Figure 6. The hardness curve shows secondary hardening due to precipitation of carbides in matrix. The f increased remarkably from the tempering temperature of 823 K regardless of holding time. The maximum hardness in subcritical heat treatment state (H_{STmax}) was obtained when the specimen was tempered at 873 K except for 3% V specimen which was obtained at 823 K. The f at the H_{STmax} is about 60-80 %, and hardness began to drop over the H_{STmax} temperature where transformation of austenite to pearlite occurred. The highest H_{STmax} value was obtained in the specimen treated for 14.4 ks except for 3% V specimen.

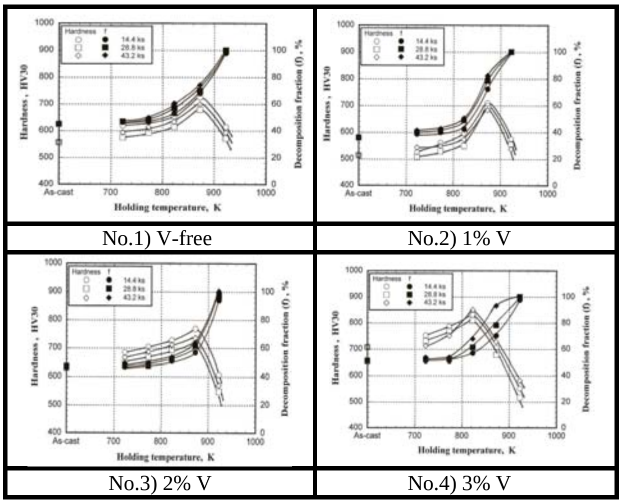


Figure 6. Relationship between macro - hardness, decomposition fraction of austenite (f) and holding temperature of 16%Cr-2%Mo cast irons without and with V.

Influence of f on hardness is shown in Figure 7. Regardless of V content, hardness increased to the maximum value and then decreased with an increase in f. At the same f value, hardness of V-bearing specimens was higher than that of V-free specimen. The highest hardness was obtained in 3% V specimen. It can be considered that some special vanadium carbides could precipitate secondarily in the matrix.

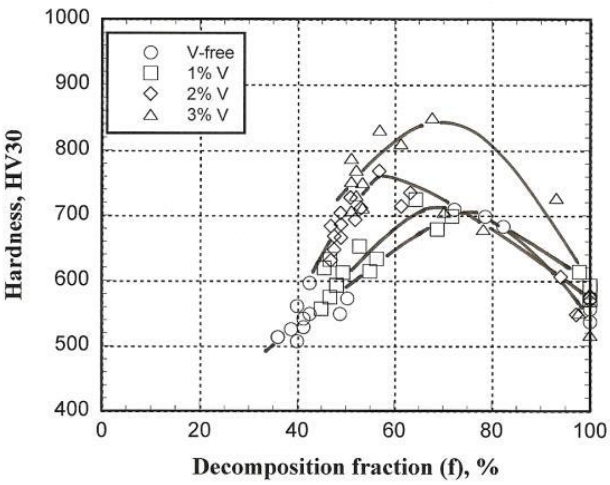


Figure 7. Relationship between hardness and decomposition fraction of austenite(f) of specimens shown by individual data.

Here, the H_{STmax} obtained from all specimens were connected to V content and are shown in Figure 8. The H_{STmax} rose gradually as V content increased over 1%. The highest values of H_{STmax} are 848 HV30 in the 3% V specimen. Micro-hardness shows the similar behavior to Macro-hardness.

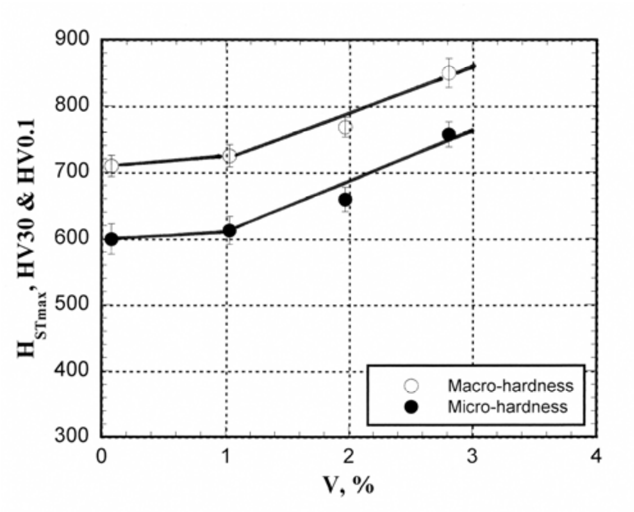
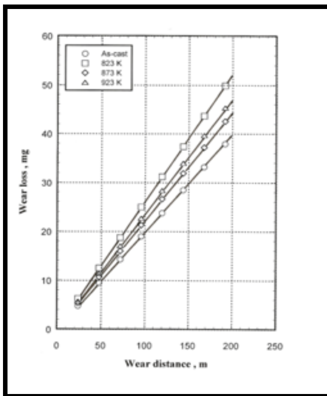


Figure 8. Effect of V content on maximum hardness in subcritical heat treatment state (H_{STmax}).

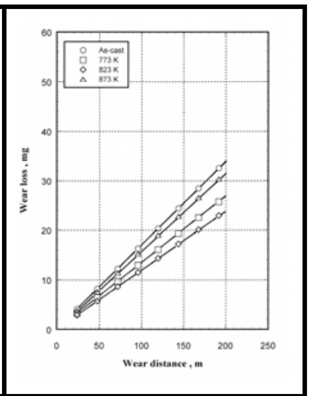
In this experiment, V shows positive effect on hardness. It is considered that hardness increased due to precipitation of special carbides from martensite by tempering or carbide reaction, which is MC carbide (2500 - 3000 HV), in addition to precipitation of chromium $M_{23}C_6$ carbide (1000 - 1520 HV).(3) The martensite transformed from destabilized retained austenite also raised hardness in the same manner as V-free specimen. It was reported that 2% V added to 17% Cr cast iron mostly dissolved into eutectic carbides, and hardness of eutectic carbide was increased. (11) This suggests that even a small amount of V can dissolve into chromium carbide and increase hardness, and that the H_{STmax} of the specimens used in this experiment should increase with increasing V content. As V content increased, V content in martensite increased. As a result, a large amount of vanadium carbides precipitated from martensite. Here, it can be concluded that the increase in H_{STmax} of V specimen might be due to precipitation of special vanadium carbides.

Abrasion Wear Test

An abrasion wear test was carried out in as-cast state and subcritical heat treatment state. The wear tests specimens were treated between 773 and 923 K for 14.4 ks, at the temperature showing the H_{STmax}, lower temperature than that at the H_{STmax} and higher temperature than that at the H_{STmax}. These temperatures refer to the hardness curve in Figure 6. The relationships between wear loss and distance of selected specimens are shown in Figure 9.Wear loss increases in proportion to wear distance. It is clear that total wear loss decreases with increasing V content. The wear rate (Rw), which is expressed by slope of straight line, is the lowest (highest wear resistance) in the H_{STmax} specimen. This proves that V could improve wear resistance of the 16% Cr -2% Mo cast iron in subcritical heat treatment process.



No.1) V-free



No. 4) 3% V

Figure 9. Relationship between wear loss and wear distance of specimens with various heat treatment. Load: 0.5 kgf

Conclusions

Following conclusions have been drawn from experimental results of this research on subcritical heat treatment behavior of 16% Cr 2% Mo cast irons with V.

(1) In as-cast state, hardness and decomposition fraction of austenite (f) increased gradually as V content increased.

(2) The hardness curve in subcritical heat treatment state showed secondary hardening due to precipitation of secondary carbides and transformation of austenite to martensite. The degree of secondary hardening was greater in the V-free specimen than that in the V-bearing specimens. The f increased greatly when the holding temperature increased over 823 K. The maximum hardness in subcritical heat treatment (H_{STmax}) stage was obtained by

treatment condition of 823-873 K for 14.4 - 43.2 ks where the f was about 60 - 80%. The H_{STmax} increased remarkably as V content increased from 1% to 3%. The highest value of H_{STmax} , 848 HV30, was obtained in the 3% V specimen.

(3) Linear relation was obtained between wear loss and wear distance. The total wear loss decreased with increasing V content. The highest wear resistance or lowest wear rate (Rw) was obtained in the specimen with H_{STmax}. Addition of V could improve wear resistance of the 16% Cr - 2% Mo cast iron in subcritical heat treatment process.

Acknowledgement

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