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Effect of C Content on High Temperature Erosive Wear Characteristics of Fe-Based V Containing Multi-Component Cast Steel with Ni

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Abstract. Hot hardness and oxidation property of target material influences greatly on the erosion behavior at elevated temperature. The correlation between hot hardness and oxidation property of multi component white cast irons and its erosion resistance were investigated, and try to estimate the high temperature erosion behavior in the study. Nine kinds of multi component white cast iron and cast steel were used in this study. Specimen were machined into a flat plate with dimension of 50 × 50 × 10 mm.

High temperature erosion test machine was used to investigate the erosive wear property of specimens at 1173K. Alumina grits (average diameter: 1.16 mm, hardness: 1250 HV_1) which were used as impact particles were heated to 1073K and shoot on the heated specimen by hot air at the velocity of 100 m/s. The total particle loading was 2 kg.

In order to clarify the correlation of hot hardness, oxidation property and the erosion resistance of specimens, hot hardness test was carried out specimens, to estimate erosion damage caused by solid particle. Hot hardness of specimens showed a value comparable to 200-250HV. Result of erosion and oxidation tests, erosion rate and amount of oxidation of the specimen were suppressed by Ni addition. It suggested that the more amount of Ni contents, the lower the erosion rate and the less the amount of oxidation.

Introduction

Erosion is a kind of surface damage that caused by the impact of dispersed particles in solid or gas flow [1, 2]. It was recognized as a reason of material failure and may cause serious accidents in the manufacturing and transportation industry, especially at elevated temperature [3-7].
As an instance, high temperature erosion happens in the manufacturing process of pig iron when iron ore and coke are falling through the revolving chute to feed into the blast furnace. During the feeding procedure, iron ore and coke first blast onto the surface of revolving chute and then in the falling process they would continue hitting on the side wall of the revolving chute due to its revolutional motion. Therefore, the surface of the revolving chute would then be seriously damaged by the continuously impact of ore and coke due to wear. In this situation, the temperature of the revolving chute would be 873 ~ 1173 K. Therefore, it is urgent to develop new wear resistent materials which could be used at that temperature.

According to the previous research, the reduction of matrix hardness at elevated temperature makes the materials display ductile characteristics. Thus, the damage of erosive wear was increased dramatically, especially at lower angles [8-12]. However, the multi-component white cast irons with the addition of carbide forming elements such as Cr, Mo, W and Nb have been proved to exhibit good resistance to erosive and abrasive wear due to the retention of hardness by carbides dispersed in the matrix [13-16]. The crystallization of carbides with high hardness in the matrix were proved to be effective to improve the erosive wear property under high temperature conditions. Furthermore, oxidation property also plays an important role in erosive wear property. Multi-component white cast irons with V addition showed lower erosive wear property because of the effect of V in the promotion of oxidation by vanadium attack at high temperature. However, multi-component white cast irons with Nb addition didn't show the promotion of oxidation. Instead, it showed good erosive wear property at elevated temperature [16]. Moreover, the effect of secondary hardening which can be obtained by secondary carbides through the heat treatment was another possible method to further improve the erosive wear property.

Ni is known as having an effect of improving the hardenability and heat resistance of the heat-treated steel [17, 18]. Even though Ni is not a carbide forming element, it will not form carbides to remain the hardness directly. However, Ni will be preferentially dissolved into the matrix compared to the other carbide-forming elements such as Cr and Mo. Then, the amount of carbide-forming elements dissolved into the matrix will be suppressed, and in contrast, these carbide-forming elements will be encouraged to form more carbides during crystallization. And the improvement of erosive wear property can be expected.

Furthermore, due to carbon (C) is closely involved with the formation of carbides, transformation properties of the matrix structure and the toughness of material [18], the influence of C content was also needed to be investigated in the present study.

Therefore, in the present study, Effect of C content on high temperature erosive wear characteristics of Fe-based V containing multi-component cast steel with Ni.

Experimental Procedure

Materials

Nine kinds of multi-component cast irons with approximately 1.0, 1.5 or 2.0 mass % of C, 5 mass % of Cr, Mo, W, V, Co and 0, 5 or 10 mass % of Ni were prepared as specimens used in Chapter 5 (abbreviated as 1.0C-0Ni, 1.5C-0Ni, 2.0C-0Ni, 1.0C-5Ni, 1.5C-5Ni, 2.0C-5Ni, 1.0C-10Ni, 1.5C-10Ni and 2.0C-10Ni). The chemical compositions are shown in Table 1.

50 kg of raw material was melted in a high frequency induction furnace at 1913 K and was then poured into a sand mold 125 mm in length and a Y-shape with a 53 × 113 mm cross section. Cut the riser of the Y-block and then mechanically machined the materials into flat plates with dimensions of 50 × 50 × 10 mm to be used as erosive wear specimens.

Table 1. Chemical compositions of specimens

(mass %)

Specimen	C	Si	Mn	Ni	Cr	Mo	W	V	Co	Fe
1.0C-0Ni	1.21	0.68	0.28	-	4.63	5.35	5.47	5.33	4.36	Bal.
1.5C-0Ni	1.67	0.69	0.27	-	4.56	5.40	5.45	5.33	4.31	Bal.
2.0C-0Ni	2.15	0.51	0.26	-	4.56	5.47	5.41	4.65	4.75	Bal.
1.0C-5Ni	0.97	0.86	0.60	5.53	4.54	4.74	4.77	5.14	5.15	Bal.
1.5C-5Ni	1.51	0.95	0.92	6.34	4.51	4.72	4.77	5.30	5.11	Bal.
2.0C-5Ni	2.25	0.93	0.65	5.10	4.82	4.67	4.77	5.45	5.07	Bal.
1.0C-10Ni	0.89	0.80	0.56	9.92	4.31	4.49	4.54	4.84	4.85	Bal.
1.5C-10Ni	1.54	0.97	0.88	10.10	4.21	4.82	4.97	5.34	4.64	Bal.
2.0C-10Ni	1.80	0.85	0.38	10.06	4.17	4.81	4.71	4.93	4.23	Bal.

P: ≤ 0.02, S: ≤ 0.02

Metallographic observation

Microstructure of the specimens was observed after etching by 3% nitric acid-ethanol by using an Optical Microscope (OM, ECLIPSE MA200, Nikon, Japan). Scanning Electron Microscopy (SEM, JSM-6510A, JEOL, Japan) and Energy Dispersive Spectroscopy (EDS, JED-2300, JEOL, Japan) were used to observe the shape of the carbides and investigate the type and area ratio of carbides. The area ratio of carbides in the matrix was measured by perform binarizing on each photo taken by SEM under 400X magnification. The average value of 5 different photos by calculating the area ratio of the black areas using image processing software was recognized as the area ratio of carbides.

Hardness measurement

Vickers hardness of the specimens was conducted using an AVK-HF type high temperature hardness testing machine (Mitutoyo, Japan). Specimens were prepared to be dimension of 7.0 × 7.0 × 5.0 mm, and test surfaces of the specimens were polished before each test. Test temperatures were room temperature (R.T.) and 1173±5 K (which were consistent with the erosion test temperature). Argon gas was blown into the chamber to restrict oxidation of the test surface. In each test, hardness was tested at 7 locations using a diamond indenter after maintaining the specimen at a certain temperature for 5 min. Test load was 98 N and loading time was 10 s. Hardness was calculated according to diagonal measured at test temperature.

Evalution of erosive wear characteristics

In this study, a high temperature erosion test machine was used to investigate the erosive wear property of materials at elevated temperature. The detail of this test machine has been described in the earlier works [9]. The machine has three furnaces which can control the temperature of test specimen, eroded particles and hot air, separately. Irregular alumina grit with an average diameter of 0.85~1.18 mm and hardness of 1250 HV was used as impact particles. During erosion test, alumina grits were heated to 1073 K and shoot on the surface of specimen (heated to 1173 K) by hot air (heated to 773 K) at the velocity of 100 m/s (particle velocity about 30 m/s). Each shoot, 500 g of alumina grits were heated and impacted on the specimen. And then, another 500 g of alumina grits were added into the particle furnace to be heated (heating time: about 30 min). This process was repeated for four times which made the total particle loading 2 kg. Impact angle was 30 deg. to compare the largest erosion rates of all specimens.

Oxidation test was performed at 1173 K for 3.5 h, which was consistent with the erosion test conditions.

The mass of the test specimen was measured before and after each test. In order to judge the erosive wear property of materials with various density, volumetric removal divided by the total feed of impact particles was took as erosion rate [1]. Erosion scar of the worn surface and the vertical section near the erodent surface were examined to determine the possible erosion mechanisms.

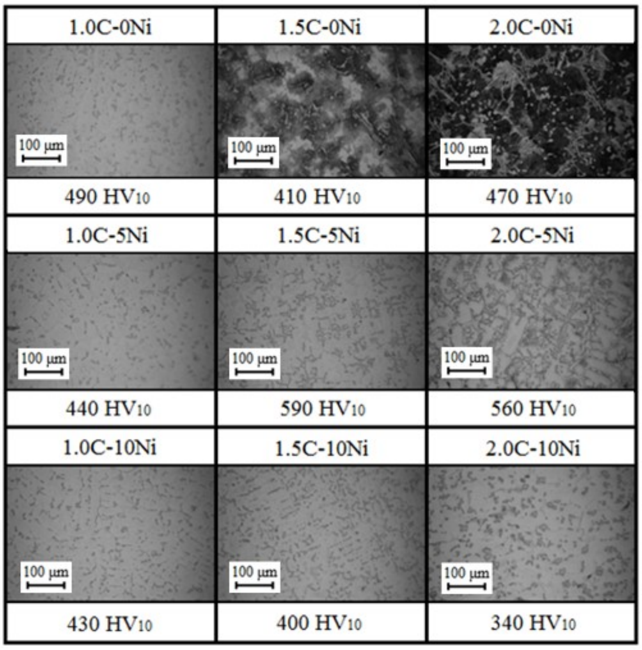
Results and Discussions

Result of Metallographic observation

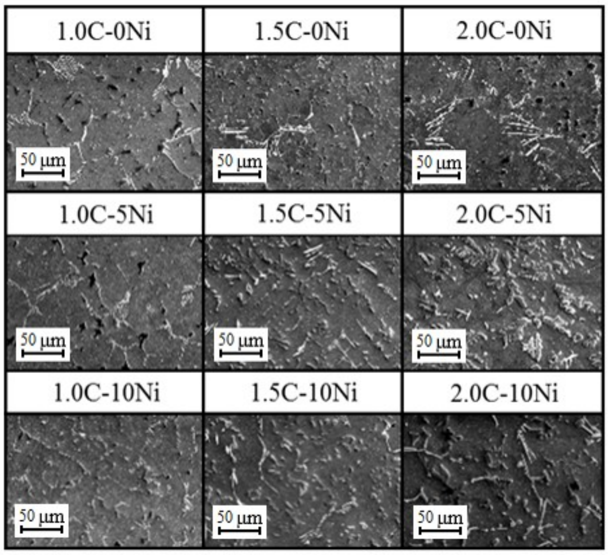
The microstructure and Vickers hardness of specimens are shown in Fig. 1(a). The matrix of 1.5C-0Ni and 2.0C-0Ni was bainite and austenite, while the matrix of the other materials was austenite. The hardness of all specimens was among 340~590 HV10.

SEM was conducted to calculate the carbide area ratio of specimens. SEM images are shown in Fig. 1(b) and carbide area ratio of specimens is shown in Fig. 2. It can be seen that in all specimens, the carbide area ratio improved with the content of C increased. On the other hand, focusing on Ni addition, the carbide area ratio showed the same degree in the 1.0 mass % C materials, and 1.5 mass % C materials showed a tendency to increase with the increasing Ni addition. However, in the 2.0 mass % C materials, 2.0C-5Ni showed the highest area ratio of about 31.60 %.

The types and shapes of carbides have been clarified in previous studies. Compared the results of SEM and EDS mapping results of specimens shown in Fig. 3, the reactions of V and C were noticeably observed in the granular or petal-shaped part of all specimens, which were confirmed as MC carbides mainly composed of V. In addition, reactions of W, Mo and Cr were observed in the needle-like and lamellar-shaped portions, which were confirmed as complex carbides of M2C carbides mainly composed of W and Mo or M7C3 carbides mainly composed of Cr. There was no difference in type of carbides for materials with different Ni addition.



(a) Microstructure and hardness



(b) SEM images

Figure 1. Microstructure, hardness (R.T.) and SEM images of specimens

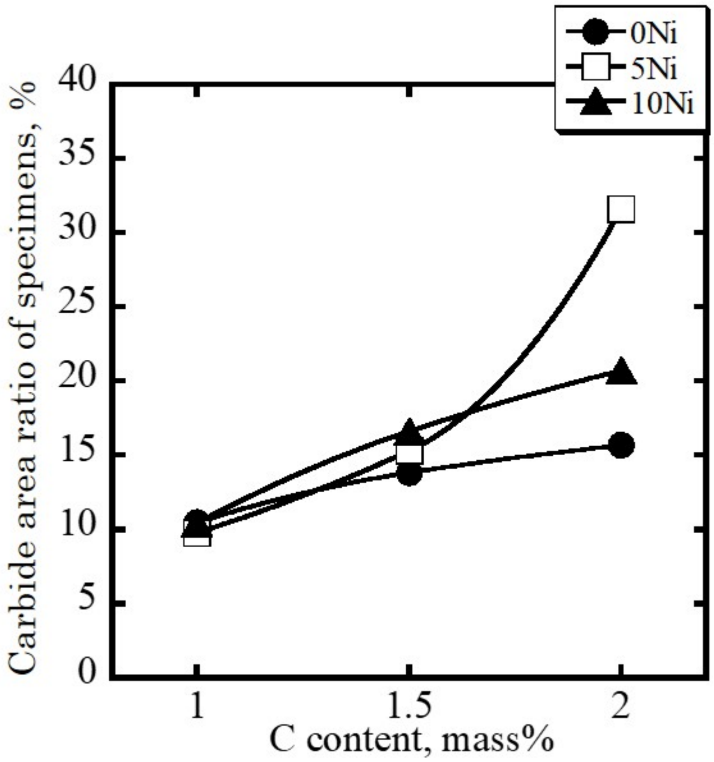


Figure 2. Carbide area ratio of specimens

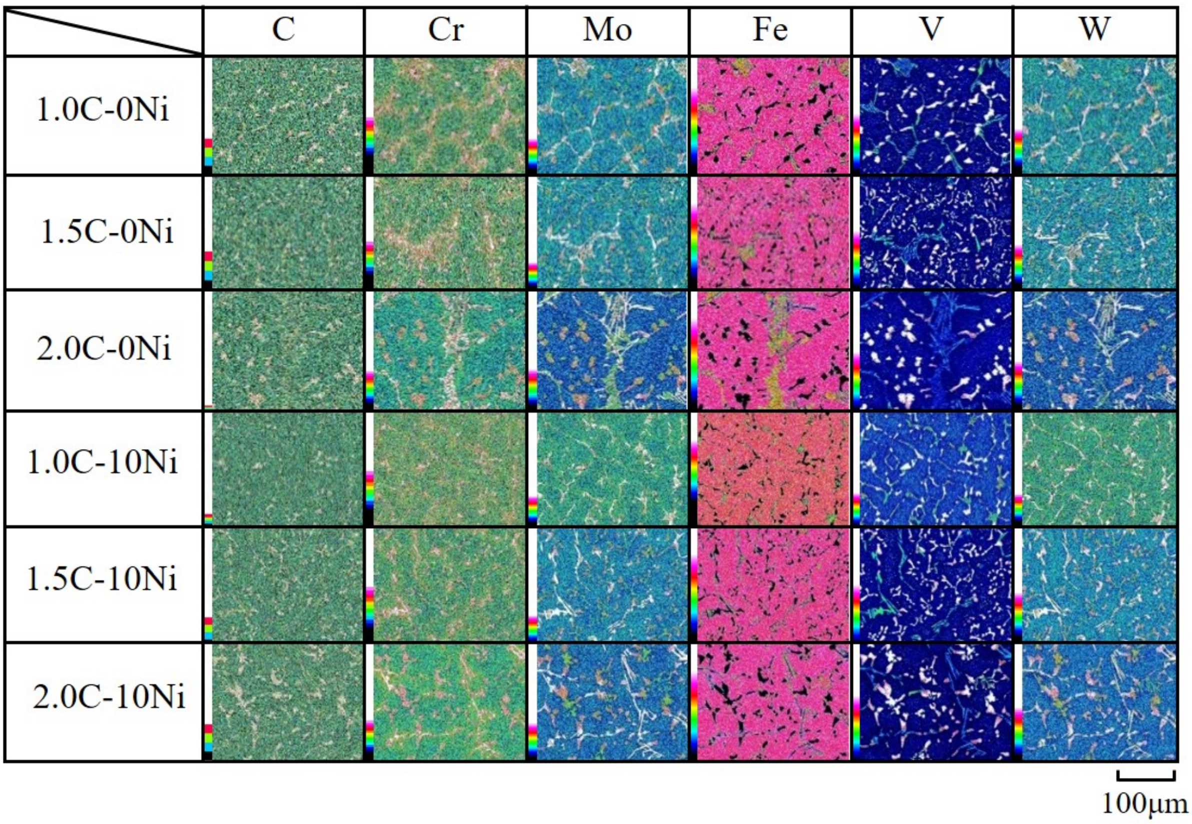


Figure 3. EDS images of specimens

Result of high temperature erosive wear test

The high temperature erosive wear test results at impact angle of 30 deg. are shown in Fig. 4. As results, in specimens with the same amount of C content, the erosion rate decreased with the increase in Ni addition amount, and 2.0C-10Ni showed about 2.6 times better high temperature erosion wear characteristics than 2.0C-0Ni material. On the other hand, focusing on the C content, erosion rates of 0 mass % Ni materials showed an increase tendency with the increase of C content and erosion rates of 5 mass % Ni materials showed the same value regardless of the C content. However, in 10 mass % Ni materials, erosion rates showed a tendency to decrease with the increasing C content.

In the previous studies, the higher the carbide area ratio, the better resistance to erosive wear was exhibited. However, the erosion rates have no correlation with the amount of carbides in the specimens of this study. The investigation of factors other than the carbide area ratio is considered necessary. Therefore, high temperature Vickers hardness tests and oxidation characteristics of specimens were conducted at experimental temperature (1173 K).

Result of hot Vickers hardness test

Since it has a great influence on erosive wear characteristics of specimens at elevated temperature, high temperature Vickers hardness was measured at experimental temperature (1173 K). The results are shown in Fig. 5. It can be seen that hardness tended to increase as the C content increased in all specimens. Focusing on the amount of Ni addition, the hardness of the 1.0 mass % C materials were all in the same degree (about 170 HV10), and the hardness increased with the increase of Ni addition in the 1.5 mass % C materials from 185 HV10 to 205 HV10. In 2.0 mass % C materials, however, 2.0C-5Ni showed the highest hardness of 251 HV10. These tendencies were in accordance with the carbides' area ratio results, and 2.0C-5Ni which showed the highest carbide area ratio showed higher hardness comparing to the other specimens. However, there is still no correlation between the high temperature Vickers hardness and the experimental results of erosion tests. Therefore, the oxidation characteristics, which is one of the important factors for heat and wear resistant materials under high temperature environment, was investigated.

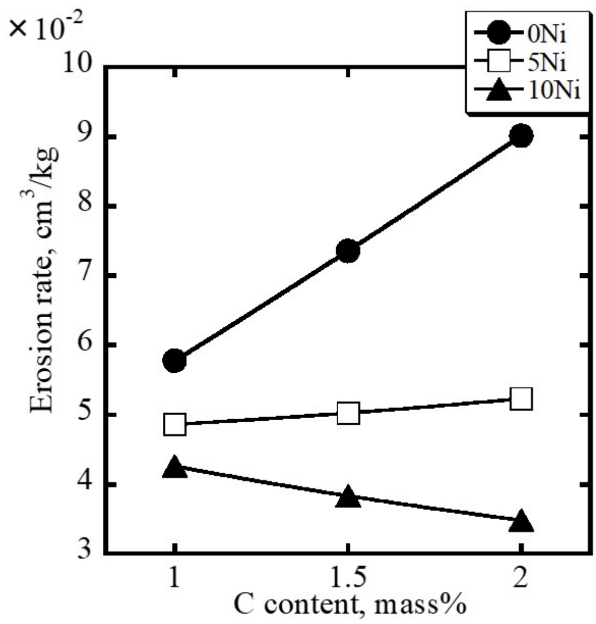


Figure 4. Erosion rate of specimens as a function of C content at 1173 K

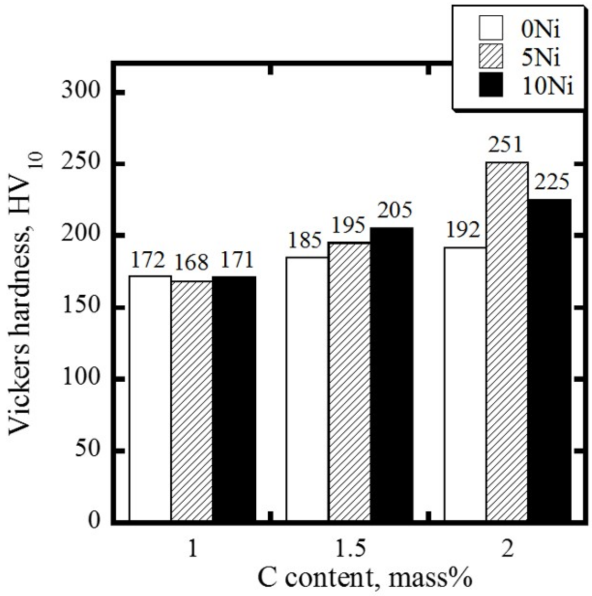


Figure 5. Vickers hardness of specimens at 1173K

Result of Oxidation Test and Oxide Layer Observation

Oxidation rates of specimens are shown in Fig. 6. Focusing on the C content, in the 0 mass % Ni materials and the 5 mass % Ni materials, the oxidation rates increased with the increase of the C content, and the 10 mass % Ni materials showed the same lower degree of oxidation rates. It indicates that materials with lower C content has a better resistant to oxidation. With the addition of Ni, the resistance of oxidation increased and materials with higher C content and 10 mass % Ni addition also showed good resistance to oxidation. On the other hand, paying attention to the Ni content, in materials with the same amount of C content, the oxidation rates decreased with the Ni content increased, and the influence of the change in C content also tended to decrease. Compared with material without Ni addition, the oxidation rate of 2.0C-10Ni was reduced to about 1/8 of the 2.0C-0Ni material. From these facts, it was clarified that changing the amount of C and Ni contents contributes to the improvement of oxidation characteristics.

The influence of Ni addition on the oxide films was investigated using materials with 2 mass % C content which had the most differences in oxidation rates. The SEM observation results of oxide films are shown in Fig. 7. The thickness of the oxide films tended to narrow as the amount of Ni addition increased. The thickness of the oxide film of 2.0C-10Ni material decreased by approximately 45 μm compared to that of 2.0C-0Ni material. From these facts, it can be inferred that 2.0C-10Ni material exhibited the most excellent erosive wear resistance by suppressing the oxidation of material surface through Ni addition.

In addition, in order to investigate the influence of Ni addition on the oxide films, EDS surface analysis test was also conducted on materials with 2 mass % C content. The mapping results, since the reaction of Ni and O is remarkably observed between the oxide film and the material in 2.0C-5Ni and 2.0C-10Ni material, it is considered that with the addition of Ni, oxides of Ni and O were formed to suppress oxidation.

From the results of high temperature erosion, high temperature hardness and oxidation tests, the oxidation characteristics were improved by Ni addition, and it was considered that the influence of C content was small in 10 mass % Ni materials, so that they all showed improved erosive wear resistance. Among them, it can be inferred that 2.0C-10Ni material with the highest high temperature hardness showed excellent erosive wear characteristics.

From these facts, it is clear that the improvement of high temperature hardness and oxidation characteristics are important factors for improving high temperature erosive wear characteristics, and the addition of Ni is considered to be effective for this improvement.

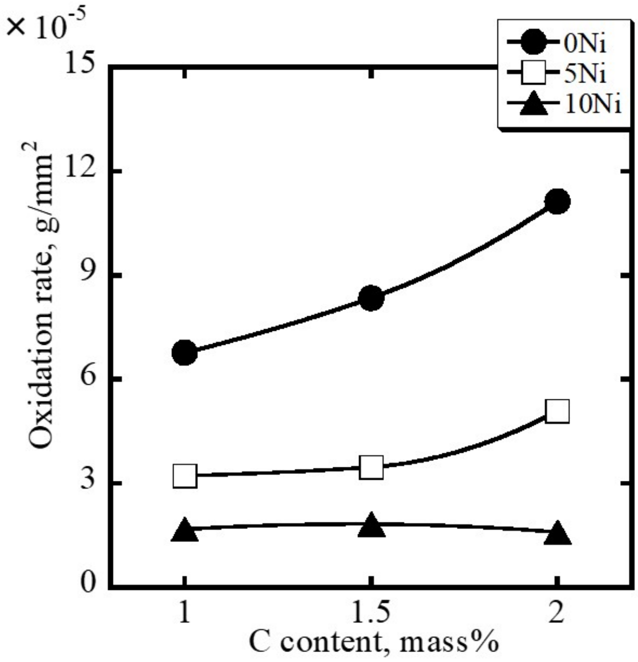


Figure 6. Oxidation rate as a function of C content of specimens

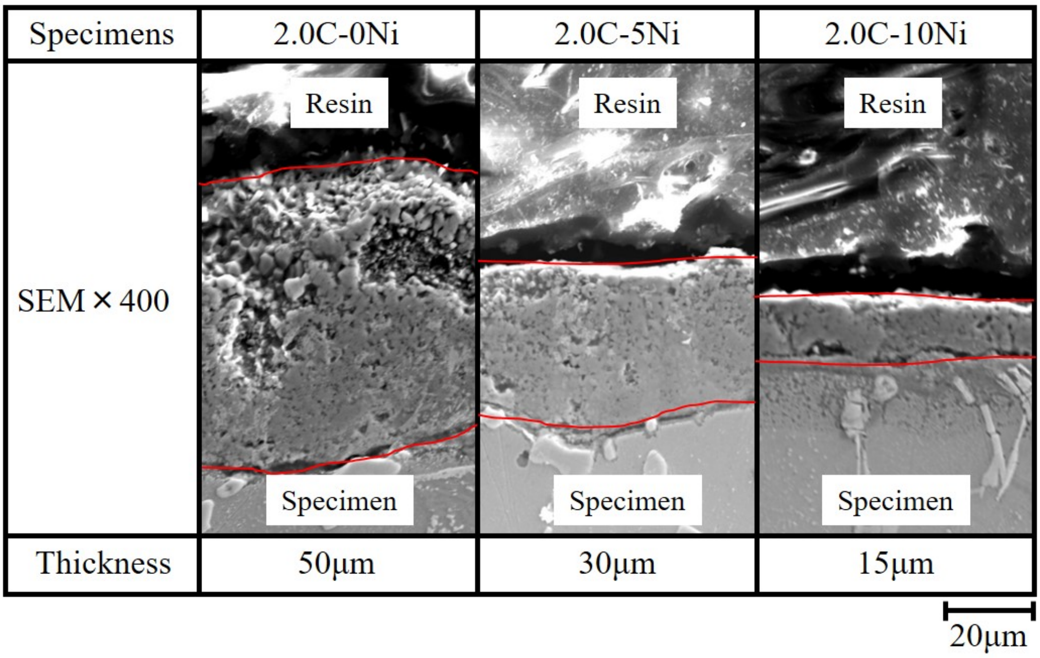


Figure 7. Thickness of oxide layer of specimens

Conclusions

In this study, nine kinds of multi-component cast irons with addition of approximately 5 mass % of Cr, V, Mo, W, Co, as well as various Ni addition of 0, 5, 10 mass % and C content of 1.0, 1.5, 2.0 mass % were prepared as specimens and the influence of C content and Ni addition on the high temperature erosive wear characteristics of V-containing multi-component cast irons was investigated at 1173 K. The following conclusions were made.

(1) High temperature hardness and oxidation characteristics greatly changed due to the changes in C content and Ni addition amount.

(2) 2.0C-10Ni material showed the best erosive wear resistance due to the excellent high temperature hardness and oxidation characteristics.

The improvement of high temperature hardness and oxidation characteristics are important factors in high temperature erosive wear. It became clear that the addition of Ni is effective for this improvement.

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