K/Na-Treated Fe-Cr-C Hardfacing Alloys with High-Impact-Abrasion Resistance

The martensitic matrix of the hardfacing alloy is changed to austenite with a K or Na additive, but hardness is attained through a dispersion of fine carbides

BY J. H. YANG AND X. B. WANG

ABSTRACT. This paper deals with K/Na-containing additives in the coatings or cores of electrodes, transforming the martensitic matrix of Fe-Cr-C hardfacing alloy into an austenitic one. The austenitic martrix hardened by the fine dispersed $(Cr, Fe)_7C_3$, together with the isolated lumpish eutectic carbide, enchance both the impact and abrasion resistance of this alloy.

The authors also found that Na doubled the effectiveness of the additive, and 50% less is needed to get better results compared to the K addition.

Introduction

Abrasive wear usually is the leading cause for machine parts worn out in service, causing a great deal of scrap metal and economic loss in production. Therefore, applying a hardface abrasion-resistant alloy onto these easily worn out parts is an effective way to prolong their service life, especially for those components used in the cement, mining and metallurgical industries.

Impact-abrasion resistance of an alloy requires its matrix not only to possess sufficient hardness, but also to contain a sufficient hardening phase. Besides hardness, plasticity of the matrix and the binding strength between the hardening phase and the matrix also play important roles. Some researchers (Refs. 1, 2) have pointed out that the matrix with a face-centered cubic lattice possesses a better ability to receive plastic deformation, and that the austenite-martensite transformation occurring through wear not only enhanced the matrix's hardness, but also consumed a part of the abrasion energy, both of which are beneficial for enhancing abrasion resistance. In light of these findings in tribology, the aim of this research is to develop a hardfacing alloy with an unstable hardened austenitic matrix to fulfill a high-impact, abrasion-resistant requirement.

It is well known that Fe-Cr-C alloy has good low-stress abrasion resistance, but owing to its poor toughness, it is prone to crack in impact service. Adding 3–5% Ni to this alloy may improve its anti-cracking property and toughness, yet it still is not suitable for strong impact service (Ref. 1).

Since the matrix hardness of Fe-Cr-Ni-C alloy is low, its abrasion resistance is reduced compared to plain Fe-Cr-C alloy.

The present research has developed an approach to solve this problem by adding K- or Na-containing additives to the coatings of the electrode of a Fe-Cr-C hardfacing alloy to improve its impact-abrasion resistance. K or Na has almost the same effect, but Na has twice the range of effective addition, and 50% less addition is needed to get a better result. Furthermore, the Na-containing additive is not so moisture absorbent as the K-containing ones, which makes it easy to handle in production or storage. Therefore, the Na-containing one seems to be more promising for the future. This technology has already been used in China to hardface or recondition large loader shovels, power crusher rollers and hammer blocks with satisfactory results.

J. H. YANG is a Professor and X. B. WANG is a Lecturer at Shandong University of Technology, Shandong, China.

Key Words

Hard Facing Alloys
Fe-Cr-C
K Addition
Na Addition
Electrode
Toughness
Abrasion-Resistant Alloy
Microstructure Study
Mechanical Tests
Matrix Transformation

The Electrode

The electrode's core wire is made of 4-mm (0.16-in.) diameter HO8A steel (China weld steel wire standard: C ≤0.10; M=0.30–0.55; Si ≤0.03; Cr ≤0.20; Ni ≤0.30; S and P ≤0.003). The coatings consist of properly proportioned metal carbonates, TiO_2, graphite and Cr-Fe, but without fluorspar. The C and Cr ranges are: C, 2.0–3.0%; Cr, 20–30%.

Cored wires tested with the FCAW process were also made of HO8A steel with flux of the same composition as the coating mentioned above.

As both K or Na are very reactive, they cannot be added directly. Our additive containing 10–15% K/Na was prepared through reducing K_2CO_3 or Na_2CO_3 at high temperature in melting. All covered electrodes were baked at 250°C (482°F) for 1 h before using. Most SMAW was conducted on an AC welding machine with welding current of 150 A.

Test Procedures

Test Piece Preparation

The base metal (low-carbon steel plate: C=0.2%) was cut to 200 x 70 x 15 mm (7.7 x 2.8 x 0.6 in.) and clamped in a vise with the 70-mm side in the horizontal position. Without preheating, hardfacing work was done successively layer by layer. The temperature between layers rapidly rose to 400° to 500°C

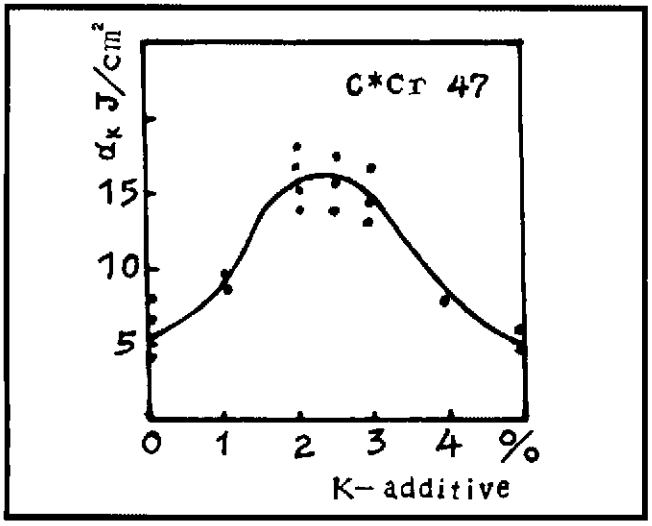

Fig. 1 — Dependence of toughness of Fe-Cr-C hardfacing alloy on amount of K-containing additives. Toughness here refers to impact value αk of the undiluted hardfacing alloy.

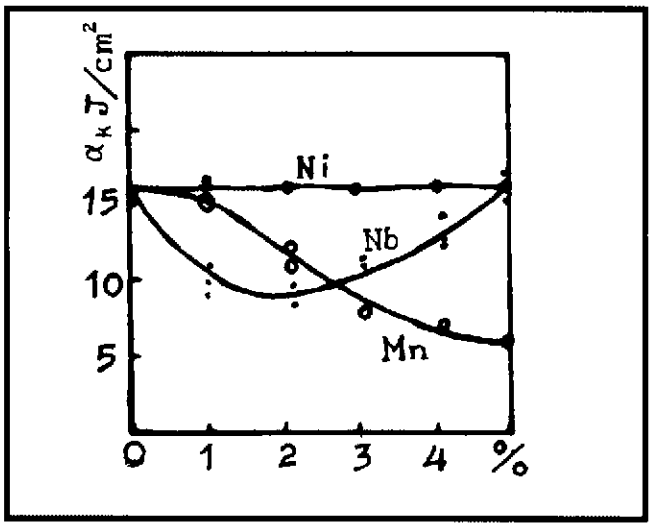

Fig. 2 — Effects of Mn, Nb and Ni on toughness of K-treated hardfacing Fe-Cr-C alloy. The % of Mn, Nb and Ni refers to deposited metal Fe-Cr-C with [C] x [Cr] x 100² ≈ 47 and 2.5% K-containing additive.

(752° to 932°F). The work wasn't completed until the surfaced thickness became greater than 15 mm (more than 10 layers). After cooling, the top and side surfaces of the hardfaced test piece were ground and cut to 10 x 10 x 55 mm (0.4 x 0.4 x 2.2 in.) without a notch. The test piece so prepared was not diluted by the base metal.

Test Results

Toughness Test

The impact tests were conducted on a China-made impact testing machine with maximum impact energy of 49 J. The test piece was placed so that the top surfaced layer was subjected to tensile stress. The test results are shown in Figs. 1 and 2, from which it can be seen that there exists an optimum amount of K/Na-containing additives for enhancement of impact resistance, and that the toughness of the test piece decreases with increases of C and Cr in the hardfaced metal. But where C is <2.7% and Cr is <27%, the toughness is still at a high level.

Table 1 — Cracking Test Results

Additive	Amount of Addition (%)	C, Cr Content [C] * [Cr] * 10,000 ≈47	≈67	≈81
		Number of Cracks		
nil	0	2–3	5	6
K-Containing additive	1	1	1	
	2	0	0	
	4	2	2	
Na-Containing additive	0.7			1
	1			0
	2			0
	4			2

Figure 2 shows the respective effects on toughness of Mn, Nb and Ni added to the proper K-containing coating. It was found that once Mn is >1% αk decreased rapidly. Nb at 2.0% gives the lowest impact value and gradually restores to its maximum at 5%, but Ni has no effect on toughness.

To verify the binding strength and the butt joint toughness of the hardfacing metal with a different base metal, the authors conducted a comparison test. Using the above-mentioned K-treated Fe-Cr30-C2.7 hardfacing electrode and C 0.2% steel as base metal, the αk (without notch) of the butt joint was 39 J/cm², while using M13 steel (Mn 10–14%,C 0.9–1.4%) as the base metal and using lower current to avoid overheating, the αk of the butt joint was also 39 J/cm², but if the butt joint was prepared with continuous welding, its αk dropped to 20 J/cm².

Cracking Test

Using a China-produced E5016 electrode (equivalent to AWS E7016), two surface restraint beads were made. Their bottom edges were 7 to 8 mm (0.27–0.31 in.) apart and 3 mm high (0.12 in.) on a 500 x 300 x 15-mm (19.7 x 11.8 x 0.59- in.) steel plate (C 0.2%). After they had been cooled down, a test bead about 200 mm long (7.9 in.) and 18 mm wide (0.7 in.) was welded between the restraint beads (using a 4-mm-diameter electrode, 170-A current, no preheating). The cracking test results are shown in Table 1, from which the following findings were summarized:

1) The weld cracking susceptability of Fe-Cr-C hardfacing alloy increases rapidly as the Cr and C contents increase.

2) With the proper amount of K/Na-containing additive, the cracking susceptability is markedly reduced and is still effective at higher C and Cr levels, but there exists an optimum range of K/Na addition.

3) The Na-containing additive is more effective at higher C and Cr levels. Its effective addition range is twice that of K. Its effective amount of addition is 50% less than that of K.

Table 2 — Water Sand Abrasion Test Results

Deposited Metal (Fe-Cr-C)	Weight Loss (mg)
[C] * [Cr] * 10,000 = 67 with 2% K-containing additive	3.1
[C] * [Cr] * 10,000 = 67 without adding K/Na-containing additive	4.1
Fe-30Cr-3.5C (HRC60 German made)	3.3

Abrasion Test

Two kinds of tests were conducted on a China-made MLD-10 abrasion tester.

Blade Type Water-Sand Abrasion Test

A batch of test pieces were hardfaced to 30 x 20 x 10 mm (1.2 x 0.8 x 0.4 in.) with different electrodes. Four pieces as a group were symmetrically placed on the periphery of the blade wheel. The wheel was mounted in a housing to which 26-mesh river sand and proper amount of water was added. After test duration of 8000 revolutions, the test pieces were dried and weighed with a 1/10,000-g balance.The weight losses are listed in Table 2.

Fig. 3 — Microstructure of conventional Fe-Cr-C hardfacing alloy. SEM photo 450X without K/Na additive. The hexagonal long columns are primary (Cr, Fe)$_7$C$_3$.

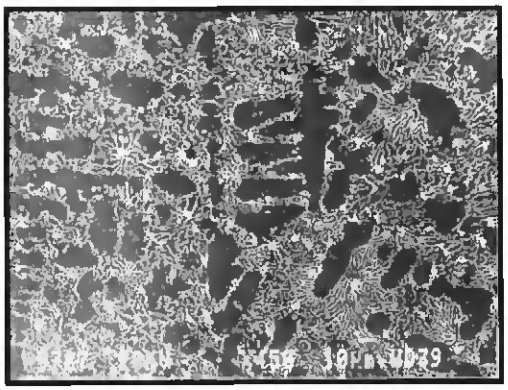

Fig. 4 — Microstructure of Fe-Cr-C alloy (SEM photo 450X). The lumpish short columnar ones are primary austenite.

Impact Abrasion Test

The test pieces consisted of upper and lower ones. The upper ones were rectangular slabs hardfaced to 30 x 10 x 10 mm (1.2 x 0.4 x 0.4 in.). They were placed on the bottom of a falling weight (5 kg) with an impact energy of 5 J, which had been adjusted by its falling height.

The lower ones were made of 0.2%C steel with their circumference hardfaced with three layers with the test electrodes and ground to 5-mm-diameter electrodes.The ring was fixed onto the spindle of the tester. The weight losses after 8000 impacts are listed in Table 3. It was found that the end of the upper test piece of Fe-30Cr-3.5C without K addition (HRC 60) had broken to pieces, while that of Fe-13Cr-0.25C with HRC 56 was plastically deformed and cracked. But that of the K treated Fe-Cr-C was found neither cracked nor plastically deformed. It is obvious that K/Na-treated Fe-Cr-C hardfacing alloy possesses very good impact-abrasion resistance.

Table 3 — Impact Abrasion Test Results

Deposited Metal	Wt Loss of Lower Test Piece (mg)	Wt Loss of Upper Test Piece (mg)
Fe-Cr-C [C] * [Cr] * 10,000 = 67 with 2% K-containing additive	19.6	9.0
Fe-30Cr-3.5C (HRC60 German)	174.9	132.0
Fe-13Cr-0.25C (HRC56)	36.2	23.6

Determination of Retained K and Na

Through x-ray fluorescence analysis, the amounts of K and Na retained in the deposited metal were found as:

1) For the electrode with K, Na addition: K 0.003–0.024%, Na 0.015–0.020%. These values vary with the amount of K/Na-containing additives.

2) For the electrode without the K/Na additive, K and Na are around 0.003%. That amount might come from the water/glass, which was used as a coating binder.

From the above, it is clear that reactive K/Na in the electrode coating can be transfered to the deposited metal, though the amount is very small.

Microstructure Stody

SEM Ohservation

Specimens were cut in both parallel and perpendicular directions with respect to the base metal. The microstructure of Fe-30Cr-2.8C without K/Na additive was comprised of coarse hexgonal columnar primary carbide plus eutectics with fine needle-like structures, or a vermicular eutectic carbide — Fig. 3. In the same alloy with K/Na addition, the primary phase is not carbide, but it is a lumpish columnar matrix (with 20% area in the viewing field) plus eutectic carbide with it being shorter and smaller size — Figs. 4–6. This can only be explained from the fact that the K/Na addition has shifted the eutectic point of the Fe-Cr-C system to the higher C and Cr concentration side, making the hypereutectic crystallization become a hypoeutectic one; though the mechanism of this change is not yet clear to the authors at the moment.

X-Ray Phase Constituent Analysis

The phase constituent in the deposited metal was verified through x-ray analysis — Figs. 7, 8. These figures show either primary or eutectic carbide in the deposited metal without K/Na addition as (Cr, Fe)$_7$C$_3$, while the matrix is α-Fe(Cr) (martensitic) and γ-Fe(Cr) (austenitic), and the diffraction peak of $(220)_\gamma$ and $(221)_\alpha$ are at the same intensity level. From this observation, the amount of γ-Fe(Cr) and α-Fe(Cr) were determined as 83% and 17%, respectively.

In the deposited metal from the hardfacing electrode with K/Na addition, the carbide is (Cr, Fe)$_7$C$_3$, but there exists only γ-Fe(Cr) in the matrix.That implies the addition of K/Na transforms α-Fe(Cr) into austenitic γ-Fe(Cr).

Microhardness Determination

The microhardness of the matrix in the deposited metal was measured and listed in Table 4. It shows that the microhardness of the matrix α-Fe(Cr) in the deposited metal Fe-Cr-C without K/Na addition is as

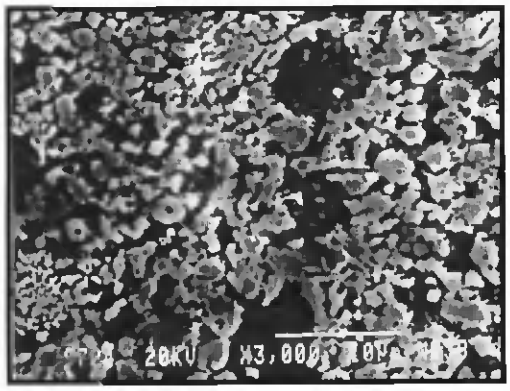

Fig. 5 — Microstructure of Na-treated Fe-Cr-C hardfacing alloy (SEM photo 3000X). The alloy has the same composition as that in Fig. 3. Dispersed phase can be faintly seen in the lumpish primary austenite.

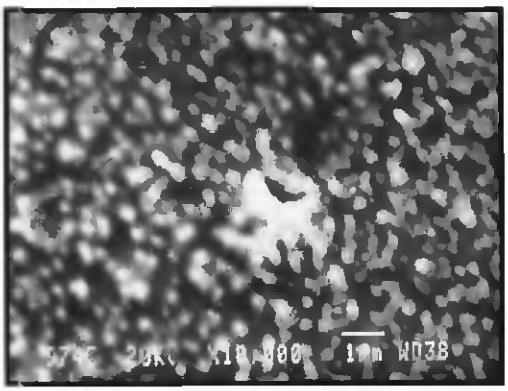

Fig. 6 — Matrix of Na-treated Fe-Cr-C alloy (SEM photo 10,000X), magnified from primary austenite in Fig. 5. White particles are (Cr, Fe)$_7$C$_3$ with diameter of 0.1–0.2 μm.

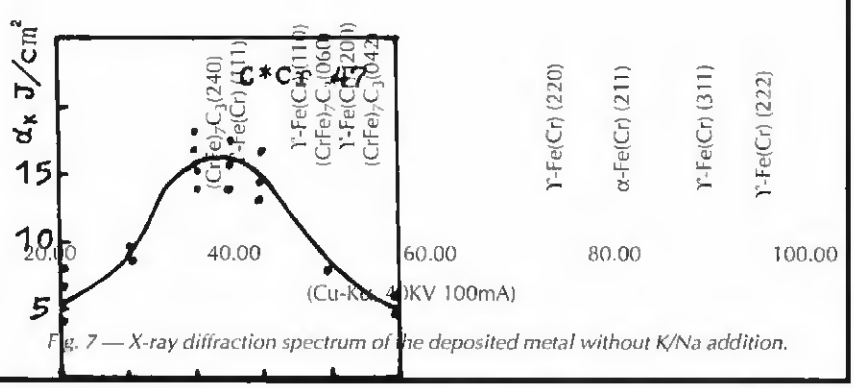

Fig. 7 — X-ray diffraction spectrum of the deposited metal without K/Na addition.

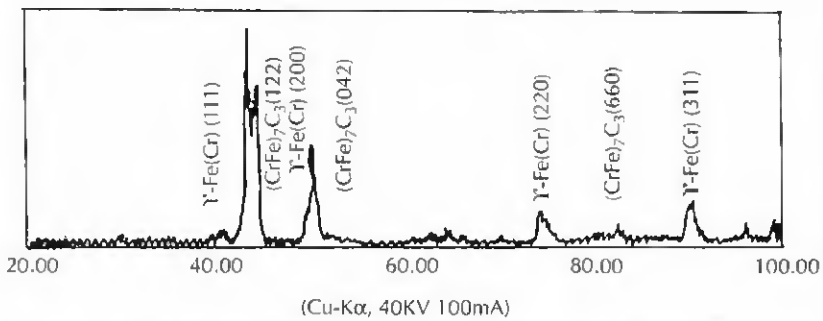

Fig. 8 —X-ray diffraction spectrum of the deposited metal with K addition.

Table 5 — Cr Content (%) through X-Ray Energy Spectrometer Analysis

Structure	With K Addition: Point Scanning 1	Point Scanning 2	Area Scanning
Matrix	20.00	37.11	23.42
Eutectic Carbide	46.16	46.80	
Area (*100)			29.68
	Without K Addition: Point Scanning 1	**Point Scanning 2**	**Area Scanning**
Matrix	18.12	18.20	19.00
Primary carbide	63.59	66.07	
Eutectic carbide	48.68	50.47	
Area (*100)			31.90

Fig. 9 — Microstructure of same Fe-Cr-C as that of Figs. 5 and 6 but with K addition (TEM photo 200 kV, 30,000X in dark field). The white hexagonal particles are dispersed (Cr, Fe)$_7$C$_3$).

Fig. 10 — Matrix of Fe-Cr-C hardfaced metal without K/Na addition (TEM photo 200 kV, 50,000X, martensite).

Table 4 — Microhardness of Matrix of Different Fe-Cr-C Hardfacing Alloys

Sample	Hardness Range (HV)	Statistical Average (HV)
Plain Fe-Cr-C	508–528	518
Fe-Cr-C Alloy with 2% K-containing additive	456–490	476
Fe-Cr-C alloy with 4% K-containing additive	666–678	672

high as HV 508–528. That hardness level implies that the matrix is martensitic. This inference was confirmed by later TEM observation. It was also found that the microhardness of the austenitic matrix in the Fe-Cr-C alloy with K/Na addition increases with the amount of K/Na addition. That is to say the retained K/Na not only has the power to austenize the matrix, but also has the power to harden it. However, compared to the toughness and cracking tests, when the microhardness of the austenitic matrix exceeds HV 666, the toughness and anticracking property of the deposited metal reduces markedly.

X-Ray Energy Spectrometer Analysis

Test results listed in Table 5 revealed: 1) The average Cr content of the austenitic matrix of the deposited metal with K addition was 23.42%, but through point scanning over microzones, it was found that the Cr distribution is very inhomogeneous, varying from 20–37%; 2) The average Cr content of the martensitic matrix in the deposited metal without K/Na addition was lower than that shown above (only 19%), but rather homogeneous; 3) Cr content in primary (Cr, Fe)$_7$C$_3$ was high, up to 63–66%, while that in eutectic (Cr, Fe)$_7$C$_3$ was only 46%; 4) Through larger area (100X) scanning, the overall Cr content of the test piece was 29.68% for those with K/Na addition and 31.90% for those without K/Na addition, which are very consistent with that obtained from conventional chemical analysis, that being 29.83% and 31.83%, respectively. This may explain why the austenitic matrix has higher Cr content as compared with the matrix without K/Na addition and why its austenitic matrix can be retained at room temperature.

TEM Analysis

As the Fe-Cr-C alloy is very hard and brittle, especially without the K/Na addition, it is very difficult to prepare a film specimen from this alloy. Through careful grinding and with the help of an

ion thickness reducing instrument, we successfully prepared a film specimen for our TEM test.

Under 30,000X magnification of the film taken from Fe-Cr-C alloy with K addition, a fine hexagonal second phase dispersed in the austenitic matrix was clearly observed — Fig. 9. By means of electron diffraction, this second phase had been labeled as typical $(Cr, Fe)_7C_3$. Its existence could explain why the austenitic matrix becomes hardened by K/Na-containing additives, while those without the K/Na addition have a martensitic matrix — Fig. 10.

Conclusion

1) The proposed K/Na-containing additive added to the coating or flux cores of the Fe-Cr-C hardfacing electrode can transfer the reactive K or Na element to the deposited metal. Though their retained amount is very small, they still have a strong power to change the microstructure of the deposited metal.

2) The K/Na addition can transform the martensitic matrix of the deposited metal of hardfacing Fe-Cr-C alloy into an austenitic one, and shift the eutectic point of Fe-Cr-C alloy to a higher C-Cr concentration, so that primary austenite becomes prevailing instead of the primary coarse columnar $(Cr, Fe)_7C_3$ that previously existed in the conventional Fe-Cr-C alloy.

3) There exists much dispersed $(Cr, Fe)_7C_3$ microparticles in the austenite, which makes the matrix harden further but without sacrificing its toughness.

4) The long columnar eutectic carbide $(Cr, Fe)_7C_3$ previously distributed in network pattern becomes separated, lumpish and shorter, which is beneficial to the improved toughness and anticracking property of this alloy.

5) The microstructure is changed by the K/Na-containing additive in the coating of Fe-Cr-C hardfacing electrode. This proprietary (Ref. 5) technology offers an alloy that possesses good toughness, good anticracking property and superior impact-abrasion resistance, which has proven satisfactory in many practical engineering applications in China.

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