Abrasion and Impact Wear Resistance of the Fe-based Hardfacing Weld by Dispersing the Recycled WC

N. H. Kang, H. B. Chae, J. K. Kim and J. H. Kim

Abstract

The abrasion and impact wear resistance were investigated on the hardfacing weld dispersed with the recycled hard metal(HM). The HM was composed of the tungsten carbide(WC) reinforced metal matrix composite. The cored wire filled with the 35 wt.% HM and 0-6 wt.% of the alloying element, Fe-75Mn-7C(FeMnC), was used for the gas metal arc(GMA) welding. The FeMnC addition to the 35 wt.% HM did not improve the abrasion wear property since the amount of the tungsten carbide formed was decreased with respect to the FeMnC amount. However, the 6 wt.% FeMnC addition to the 35 wt.% HM exhibited the better impact wear resistance than the hardfacing weld by the 40 wt.% HM.

Key Words : Hardfacing, Tungsten carbide, Abrasion wear, Impact wear, Recycled hard metal, Cored wire.

1. Introduction

The hardfacing weld is the method to improve the wear resistance of the mechanical parts, in which the hard metal powder is dispersed on the substrate, e.g., mild steel and stainless steel[1]. The WC-based hardfacing alloys are normally used for the industrial part, where the excellent wear property is needed[2,3]. However, the WC is such a expensive material that the recycled WC powder is needed to produce the hard metal cored wire[4,5].

The authors reported that the weld exhibited the abrasion wear resistance significantly improved by using the cored wire of the 30-40 wt.% recycled WC[4]. The improvement of the abrasion wear was because of the increased amount of the tungsten carbide formed. The tungsten carbide formed had a W_6C structure instead of a WC. Due to the brittle martensite matrix and the lower hardness for the W6C than that for the WC , it needs to develop the method for the improvement of the impact wear property.

To improve both the strength and wear property, the replacement of the matrix from the martensite to the austenite is recommended for the purpose of increasing the bonding between the carbides. The elements of C, N, Ni, and Mn act as an austenite stabilizer for the Fe-based alloys[6], and the Mn is known to increase the strength of the austenite. The carbon produces the carbide by combining with the tungsten. For this reason, it is expected to lead the austenite formation and sustain the strength of the matrix by adding the Mn and C.

This study investigates the effect of the Mn and C amount on the abrasion and impact wear property from the recycled WC-dispersed hardfacing weld. The wear resistance is examined through the microstructural behavior and the amount of the carbide formed.

2. Experimental details

The hardfacing weld, which was produced by

N. H. Kang, H. B. Chae, J. K. Kim, and ***J. H. Kim*** : Advanced Welding & Joining Technology Team, Korea Institute of Industrial Technology, Chonan, Korea
E-mail : nhkang@kitech.re.kr

30-40 wt.% hard metal (HM), improved the abrasion wear resistance because the amount of the austenite and the carbide was increased[4]. The microstructure of the 35 wt.% HM weld consisted of the martensite and the austenite. The effect of the Mn and C will be investigated on the behavior of the microstructure and wear property. This study used the metal cored wire of ϕ2.4 mm, which was produced from the 35 wt.% HM and 0-6 wt.% Fe-75Mn-7C (FeMnC) alloying element. The compositions of the sheath and the recycled hard metal powder are shown in Table 1, and more details on the production of the metal cored wire are noted in the reference[5]. The metal cored wire of the 40 wt.% HM is also produced for the purpose of comparing the impact wear property with the hardfacing weld of the 35 wt.% HM + 6 wt.%FeMnC.

Table 1 Composition of the recycled hard metal and sheath (wt.%)

	W	Co	Fe	Cr
hard metal	55.3	5.1	19.9	2.4
sheath	-	0.3	balanced	0.3
	Si	Ti	Ni	C
hard metal	8.6	1.7	3.4	3.6
sheath	-	-	0.3	0.2

For the hardfacing weld, the one layer of the gas metal arc welding (GMAW) was manufactured on the mild steel. The GMAW was executed for 350 amperes and 32 voltages, and 20 m*l*/min of Argon was used for the shielding gas. The distance from the torch to the work piece was 20 mm, and the torch was moved at a constant speed 8 mm/sec.

Abrasion wear property was measured as a function of the FeMnC addition by following the ASTM G 65 standard procedure B. The abrasion wear specimen was prepared to the size of 26×76×12 mm after milling the hardfacing weld. The effect of the FeMnC addition was examined for inspecting the behavior of the impact property. Although the bending and Charpy V-notch impact test were also conducted for the measurement of the impact property, these tests could not measure the impact resistance comparatively due to the brittle structure and the cracks on the weld surface[5]. Therefore, the impact wear loss by the repeated impact was examined by using the impact wear equipment (see Fig. 1)[7]. The impact wear equipment had an impacter of the pendulum style, which was made of the steel bearing ball (hardness: 900 kg/mm)[2]. The impact was applied with 1170 kg-mm, 10 impacts per minute, and 2000 impacts totally. The thickness of the hardfacing layer was above 3 mm post to the milling process, and the size of the wear specimen was 76×76×12 mm.

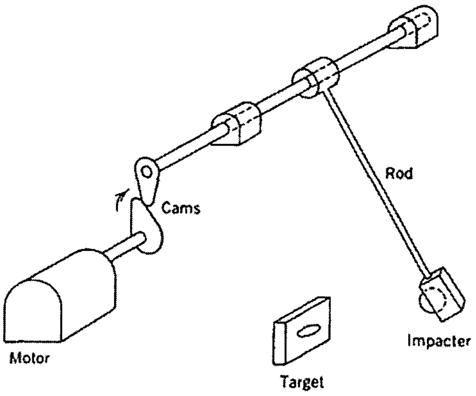


Fig. 1 Schematic diagram of the impact wear equipment[7]

The wear loss and Rockwell hardness were measured to estimate the wear resistance property. For the analysis of microstructure and phase identification, scanning electron microscopy (SEM) and x-ray diffraction (XRD) were conducted, respectively.

3. Results and discussion

3.1 Effects of the FeMnC amount to the 35wt.% HM on the abrasion wear behavior

3.1.1 Abrasion wear behavior as a function of the FeMnC amount

The abrasion wear loss was measured from the hardfacing weld of the 35 wt.% HM and 0-6 wt.% FeMnC. The result is shown in Fig. 2. The wear loss

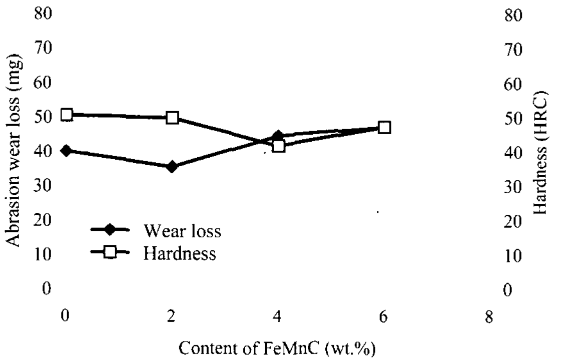


Fig. 2 Effects of FeMnC addition to the 35 wt.% hard metal on the abrasion wear loss and hardness

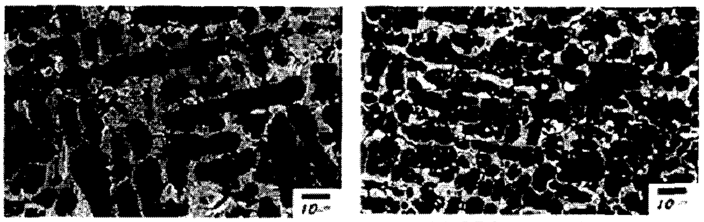
was 40.2 mg for the pure 35 wt.% HM weld, and it was decreased to 35.7 mg for the 2 wt.% FeMnC added to the 35 wt.% HM. However, the wear loss was increased to 44.8 and 47.3 mg as the FeMnC amount was increased to 4 and 6 wt.%, respectively. Although the hardfacing weld of the 35 wt.% HM + 2 wt.% FeMnC showed an improvement of the wear resistance, the improvement was not significant as compared with the wear loss for the pure 35 wt.% HM weld. Therefore, the abrasion wear loss was increased about 16% as the FeMnC was added up to 6 wt.%.

3.1.2 Relation between the hardness and the abrasion wear resistance

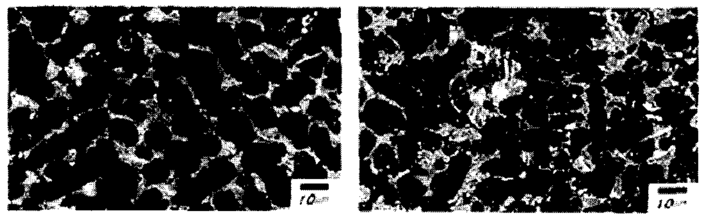
The hardness is normally known to be related with the wear resistance8,9), and it can be measured with ease. Therefore, the result of the Rockwell hardness was included in Fig. 2 as a function of the FeMnC amount. The hardness for the 2 wt.% FeMnC added to the 35 wt.% HM was 49.9 HRC, which was very similar to that for the pure 35 wt.% HM (50.6 HRC). As the FeMnC amount was increased to 4 and 6 wt.%, the hardness was varied to 41.9 HRC and 47.3 HRC, respectively. As a summary, both the hardness and the abrasion wear resistance was decreased as the FeMnC added to the 35 wt.% HM. This result wasconsistent with the previous experiments8,9) between the hardness and the wear resistance. However, the hardness is not the key factor for the behavior of the wear resistance within the authors' knowledge. This is because the variation of the hardness is not significant to explain the abrasion wear behavior, as shown in Fig. 2. Futhermore, the amount of the carbide formed was determined as the key factor for the wear property on the recycled WC-dispersed HM weld4).

3.1.3 Relation between the microstructure and the abrasion wear resistance

The microstructural behavior for the hardfacing weld is indicated in Fig. 3 to study its influence on the abrasion wear. Fig. 3(a) showed the martensite in the matrix for no FeMnC. As the FeMnC amount increased to 2 wt.%, the matrix exhibited both the martensite



(a) 35 HM (b) 35 HM + 2 FeMnC



(c) 35 HM + 4 FeMnC (d) 35 HM + 6 FeMnC

Fig. 3 Microstructural behavior as a function of the FeMnC content added to the 35 wt.% hard metal amount and the grain size decreased. For the weld of the 4 wt.% FeMnC added to 35 wt.% HM, the grain growth was occurred as compared with the 2 and 6 wt.% FeMnC weld. The specimen of the pure 35 wt.% HM indicated the carbide formed as a net shape. However, the net shaped carbide was destructed and the spherical shaped inclusion was formed as the FeMnC amount was increased.

The phase analysis was conducted as a function of the FeMnC amount. This result is shown in Fig. 4. The martensite/ferrite peaks were decreased and the austenite peaks were increased as the more FeMnC was added to the 35 wt.% HM. It does not seem to have a significant variation on the carbide peaks with respect to the FeMnC amount, even if it was very difficult to determine the carbide peak comparatively. The carbide formed had a structure of W6C instead of WC. The matrix phase was transformed from the brittle martensite to the austenite, however, the wear loss was decreased about 17% as the FeMnC was added to the 35 wt.% HM. Therefore, the phase behavior was not the key factor to explain the variation of the abrasion wear.

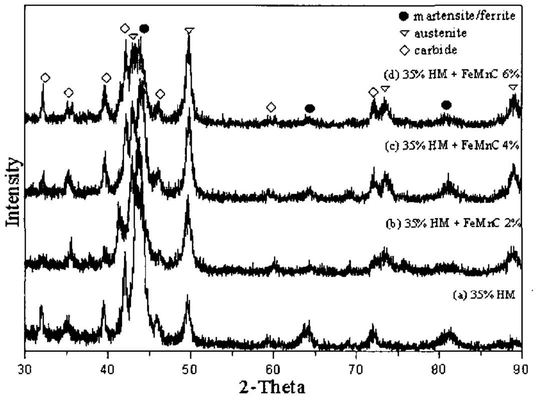


Fig. 4 Phase analysis for the 35 wt.% HM(hard metal) + FeMnC specimens

3.1.4 Relation between the carbide amount and the abrasion wear resistance

The abrasion wear property is known to be related with the carbide amount as well as the hardness10). Fig. 5 shows the carbide amount as a function of the FeMnC amount. The volume fraction of the carbide was determined from the image analysis of the SEM microstructure (Fig. 3). The carbide amount for the 35 wt.% HM weld had a 17.6 vol.%, and 17.4 vol.% for the weld of the 2 wt.% FeMnC added to the 35 wt.% HM. As the FeMnC addition was increased to 4 and 6 wt.%, the amount of the carbide formed was decreased to 12 and 11.5 vol.%, respectively. Comparing with the case of the pure 35 wt.% HM weld, the carbide amount for the 35 wt.% HM +6 wt.% FeMnC weld decreased about 35%. Therefore, the decreased amount of the carbide was responsible for the increased wear loss as the added amount of the FeMnC increased. This result corresponded to the previous result by the authors'4).

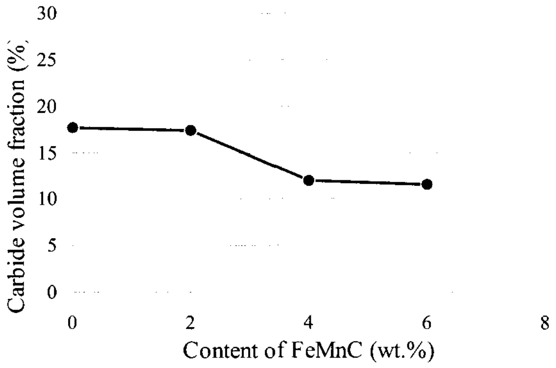
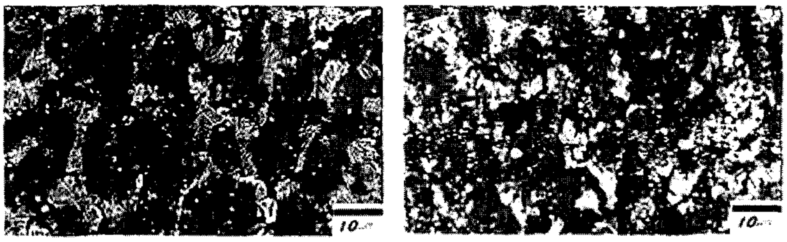


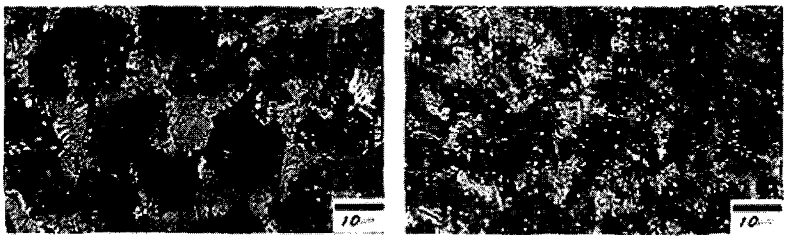
Fig. 5 Amount of the carbide as a function of the FeMnC content added to the 35 wt.% hard metal

To study the wear mechanism by the carbide, the SEM pictures were taken on the weld surface as shown in Fig. 6. The specimens including the 0-6 wt.% FeMnC indicated that both the carbide and matrix were worn through the phase. As a summary, the addition of the FeMnC made the martensite phase decreased, the austenite phase increased, and the carbide decreased. Comparing with the case of the 35 wt.% HM + 6 wt.% FeMnC weld, the hardfacing weld of the 35 wt.% HM exhibited 35% more amount of the carbide, therefore improving the abrasion wear resistance about 17%.

3.2 Effects of the FeMnC amount to the 35wt.% HM on the impact wear property



(a) 35 HM (b) 35 HM + 2 FeMnC



(c) 35 HM + 4 FeMnC (d) 35 HM + 6 FeMnC

Fig. 6 Microstructural behavior on the worn surface as a function of the FeMnC content added to the 35 wt.% hard metal

The FeMnC addition to the hard metal (HM) did not improve the abrasion wear resistance. However, it was expected to have a contribution to the impact wear resistance because the matrix was transformed to the austenite phase. For the hardfacing material, the impact resistance is not significant normally[7]. The impact wear resistance by the repeated impact needs to be studied with respect to the FeMnC amount.

To study the effect of the FeMnC addition on the impact wear property, two specimens of the 40 wt.% HM weld and the 35 wt.% HM + 6 wt.% FeMnC weld were conducted for the impact wear experiment. The result of the impact wear loss is indicated in Fig. 7. Total alloying amount of the two specimens were very similar such as 40 and 41 wt.%, respectively. The impact wear loss for the 35 wt.% HM + 6 wt.% FeMnC weld was 0.1 mg, and 0.5 mg for the 40 wt.% HM weld. The abrasion wear loss for the two specimens were also included in Fig. 7 for the purpose of considering both the impact and abrasion wear properties. Following the impact wear experiment, the microstructure on the hardfacing surface is shown in Fig. 8. The surface on the 40 wt.% HM weld showed the carbide and the matrix worn away, although the carbide played a role in improving the abrasion wear resistance. However, any destruction was not examined from the matrix of the 35 wt.% HM + 6 wt.% weld. For this reason, the FeMnC addition increased the stiffness of the austenite and the resistance on the impact wear.

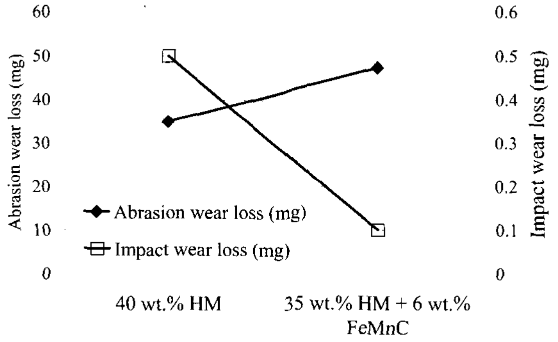
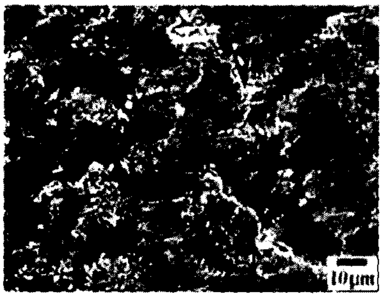


Fig. 7 Impact and abrasion wear loss for the 40wt.%HM(hard metal) specimen and the 35 wt.% HM + 6 wt.% FeMnC specimen

4. Conclusion

The abrasion and impact wear resistance were investigated on the hardfacing weld produced from the mixture of the recycled WC-dispersed hard metal (HM) and Fe-75Mn-7C (FeMnC). The 35 wt.% HM

(a) 40 HM



(b) 35 HM + 6 FeMnC

Fig. 8 Worn surfaces for the 40% wt. HM(hard metal) specimen and the 35 wt. % HM + 6 wt.% FeMnC specimen

weld exhibited the austenite and the martensite for the matrix. The FeMnC addition up to 6 wt.% increased the amount of the austenite and decreased the amount of the brittle martensite. Comparing with the case of the 35 wt.% HM weld, the addition of the 6 wt.% FeMnC decreased the carbide amount about 35% and abrasion wear resistance about 17%. However, the impact wear loss for the 35 wt.% HM + 6 wt.% FeMnC weld was improved to 0.1 mg, while 0.5 mg for the 40 wt.% HM weld.

This study did not obtain the alloying composition to satisfy both the carbide and the austenite increased. However, the FeMnC addition to the recycled WC-dispersed HM was determined to play a role in the application, for which both the abrasion and impact wear are needed

Acknowledgements

The authors acknowledge the financial support by the Technology Support Project for the Parts and the Materials.

References

1. Materials and Applications part 2, Welding Handbook-8th edition, *AWS*, Vol. 4, (1998), pp. 392-394
2. K. C. Antony : Wear resistant cobalt-base alloy, *Journal of Metals*, Vol. 35, No. 2 (1983), pp. 52-60
3. H. Ocken : Reducing the cobalt inventory in light water reactor, *Nuclear Technology*, Vol. 68, (1985), pp. 18-28
4. N. Kang, H. Chae, J. Kim, J. Choi, and J. Kim : Abrasion wear behavior of recycled tungsten carbide reinforced metal matrix composite, *Korean Journal of Materials Research*, Vol. 13, No. 12 (2003), in press
5. J. Kim, H. Chae, and J. Kim : Development of hardfacing cored welding wire by using recycled hard metal, *Final Report to Korea Institute of Industrial Technology*, (2002)
6. E. K. Ohriner, T. Wada, E. P. Whelan, and H. Ocken : The chemistry and stgructure of wear resistant, iron-base hardfacing alloys, *Metall. Trans. A*, Vol. 22A, (1991), pp. 983-991
7. P. A. Engel : Impact wear of materials, *Elsevier Science*, (1978)
8. J. Rawers, D. Govier, and D. Cook : bct-Fe formation during mechanical processing of bcc-Fe powder, *Scripta Metallurgica et Materialia*, Vol. 32, No. 9 (1995), pp. 1319-1324
9. J. Kim, G. Kim, and S. Kim : The effect of manganese on the strain-induced martensitic transformation and high temperature wear resistance of Fe-20Cr-1C-1Si hardfacing alloy, *Journal of Nuclear Materials*, Vol. 289, No. 3 (2001), pp. 263-269
10. D. J. Kotecki and J. S. Ogborn : Abrasion resistance of iron-base hardfacing alloys, *Welding Journal*, Vol. 74, No. 8 (1995), pp. 269s-278s