We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

BOOK CITATION INDEX
CLARIVATE ANALYTICS
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Effect of FeCr Intermetallic on Wear Resistance of Fe-Based Composites

S.O. Yılmaz, M. Aksoy, C. Ozel, H. Pıhtılı and M. Gür

Additional information is available at the end of the chapter

1. Introduction

Metal-matrix composites (MMCs) have higher stiffness and mechanical strength than alloys, however they have lower ductility and fracture toughness [1]. In microstructure of MMCs if a bond between particulate reinforcement and matrix has been constituted, then the composite exhibits an ability to withstand high tensile and compressive stresses. Continuous fibers, short or chopped fibers, whiskers and particulates have been used as reinforcement materials in MMCs. Discontinuous reinforcement phase composites are common due to availability, low cost, independence of mechanical properties from particulate orientation [2] and production via a vide range of manufacturing routes [3-6].

Wear is described as the removal of material from a surface in relative motion by mechanical or chemical processes [7]. The wear of the materials can be formed due to adhesion, abrasion, surface fatigue or tribochemical reaction [8,9]. The removal of material from the surface by hard particles (three-body abrasion) or by a rough counter face (two-body abrasion) is generally termed as abrasive wear. The wear resistance of a material is related to its microstructure, and the changes in microstructure may take place during the wear process [10,11] Developments of lightweight and energy-saving materials have become more numerous in the past few years in many different fields [12-16]. Recent studies [17-25] indicated that a significant improvement in the tribological properties of Fe alloys can be attained by the addition of hard carbides. Metallurgical processing, such as casting and powder metallurgy (P/M) techniques, has been successfully employed to produce anti-abrasion Fe-based composites consisting of hard carbide particles [17-25]. The strength of the as-cast composites is usually less than that of the P/M composites, and it is also possible that some large casting defects exist in the cast. These problems can largely be overcome in the P/M route. Additional advantages of the P/M process are that a high dislocation density can be introduced into the matrix, recrystalization can be prevented by carbide reinforcements, and in their structure their subgrain size is small.

Most studies [17-21] indicated that the wear resistance of MMCSs manufactured by the P/M and/or casting techniques increased with increasing volume fraction of reinforcement particulates. The wear resistance of the composite decreased with increasing reinforcement above a certain level. Jha *et al*. [26] indicated that the wear rates increased with increasing reinforcement volume fraction in the P/M sintered soft matrix alloys.

In this study, the Fe base P/M composites are reinforced with FeCr carbide complexes, soft graphite, and Cu particles to improve wear resistance benefiting from the advantage of both the energy absorption properties of the soft matrix phases and the wear resistance of the hard carbide phases. With this aim, we investigated the microstructures, wear properties and some mechanical properties (surface hardness, tensile strength and toughness of Fe base MMCSs) by using scanning electron microscopy (SEM), surface hardness (HB), tensile testing, Charpy V-notch impact and abrasive wear tests.

2. Experimental procedure

The chemical compositions of the FeCr particulates are given in Table 1. Composites containing 1 to 15wt% Fe/Cr particulates with an average particle size of about 20 μm were prepared by a conventional P/M process, which involved the steps of mixing, cold isostatic pressing (1000 MPa), degassing and sintering according to the schedules in Table 2.

The hardness of the samples were measured in the range of ±3 error band with HB hardness scale under 612.5 N load. In addition, the toughness of the samples was evaluated in the range of ±0.6 error band using Charpy V-notch specimens. The tensile strength test samples were prepared upon ASTM E8-78 L_0= 4d standard [27] and the tests were performed under Hounsfield type machine at room temperature, and by using a crosshead speed of 50 mm/min.

A pin-on disk apparatus was used for evaluating the abrasive wear resistance. For the abrasive wear tests, cylindrical billets of 12.5 mm diameter and 10 mm height were machined. Before the wear tests, each specimen was ground up to grade 1200 abrasive paper, making sure that the wear surface completely contacted the surface of the abrasive paper. Abrasive wear tests were carried out under dry sliding conditions by sliding the sample under an applied load of 10, 20, 30 and 40 N respectively over a grade 80 abrasive paper stuck to the grinding disk, which rotted at 320 rev min^{-1}. A fixed track diameter of 160 mm was used in all tests, and the duration of abrading was 60 s. Each test was conducted using a fresh abrasive paper. For each test condition, at least three runs were performed. Wear rates were obtained by determining the weight loss of the samples before and after wear tests.

Samples for microscopic examination were prepared by standard metaleographic procedures; they were then etched with %1 nital reagent and examined by optical and scanning electron microscopy (SEM). For determination of the wear mechanism of the Fe alloy and its composites, the worn surfaces and debris were examined by scanning electron microscopy, where the samples were gold coated prior to examinations.

	Element amount (wt %)					
	Cr	Fe	Si	C	P	S
Fe/Cr	64	26,30	1,80	6,84	0,02	0,038

Table 1. The chemical compositions of the Fe/Cr particulates

Treatment	Temperature (⁰C)	Time (h)	Atmosphere	Remarks
Sintering	900	1	Ar	Degassing
Sintering	1200	2	Ar	Liquid phase sintering
Solutionizing	1100	2	Ar	As solutionized

Table 2. Processing schedules of the powder metallurgy Fe composites.

3. Results and discussions

3.1. Microsturucture

The microstructures of the composites with FeCr reinforcement were investigated and optical micrograph of the sample S_1 is given in Figure 1. It was seen that, the microstructure of the FeCr reinforced MMCSs consist of ferrite matrix with dispersed FeCr particulates. The addition of graphite to the composite with FeCr particulates formed different phases (Figure
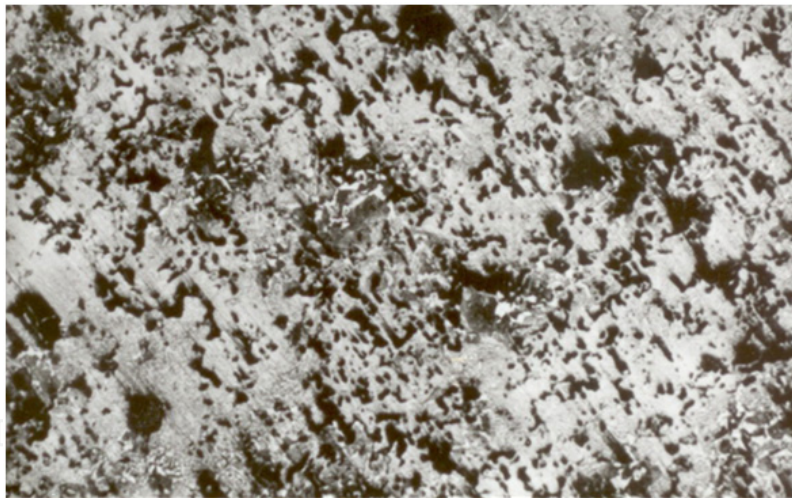
Figure 1. Optical micrographs of the sample S_1

2-Table 3). Depending on graphite amount, pearlite phase started to form around graphite particles, and increasing the amount of graphite increased the ratio of pearlite phase and M_3C carbides. Graphite grains were formed in the pearlite structure in samples with 1wt% graphite supplement. On the other hand, by increasing graphite content to 2wt%, ledeburitic structure has been formed in grain boundaries besides formation of M_3C carbides at grain boundaries and toward center of grains (Figure 3). The microstructures of the samples having soft copper supplement in the range 0.5-2 wt% with graphite (0.5wt%) and FeCr (5wt%) particulates were found near to each other, but their microstructures was different than the samples having a structure without copper supplement (Figure 4-5 and Table 4.).
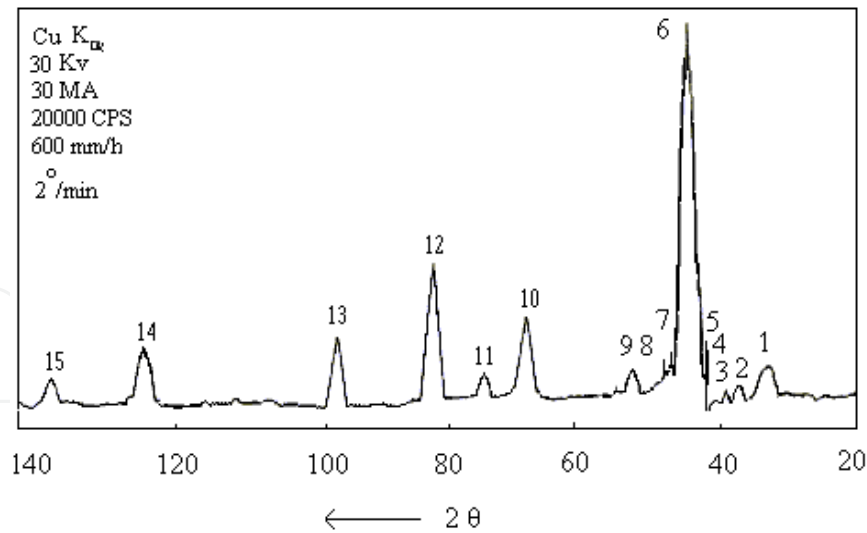
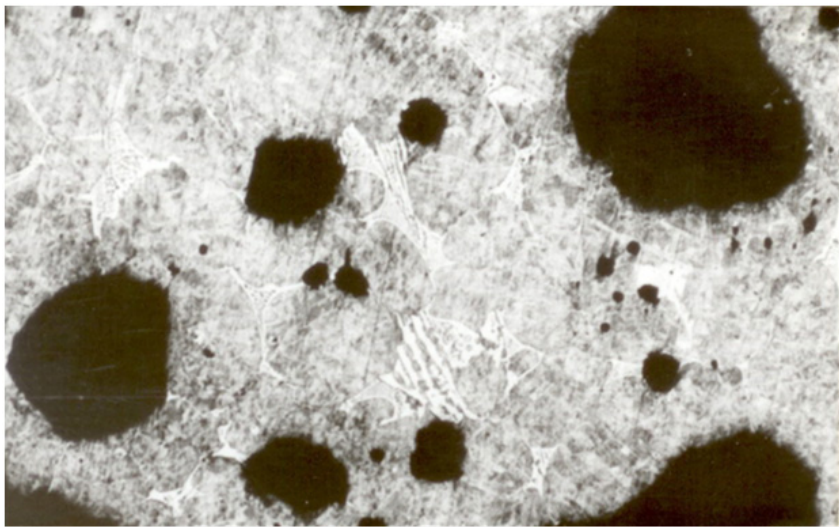**Figure 2.** X-ray difractom of the sample S$_{10}$

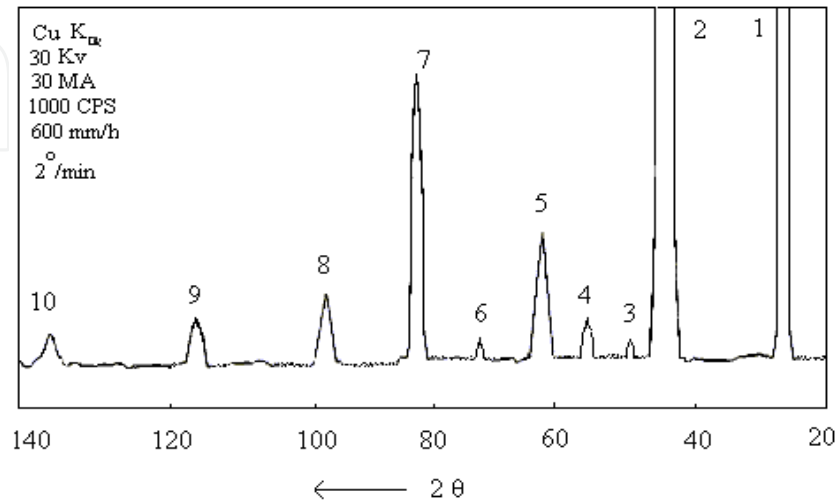**Figure 3.** Optical micrographs of the sample S$_{10}$.

Figure 4. X-ray difractom of the samples S$_{13}$

Phases		Pikes														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M₃C	S8		200				201									
	S9	101	200	110			201									
	S10	101	200		002	210	201		111	110		210				
M₇C₃	S8		211	413	101											
	S9	222	211		413	101										
	S10		222				211					413		101		
αFe	S8				110	200	211	220	310					222		
	S9			110		200	211	220	310	222						
	S10						110				200		211	220	310	222
C	S8			002		110										
	S9		002	100		110										
	S10				002		100					110				
M₂₃C₆	S8		111	200			220									222
	S9	111	200			222										
	S10			111			200						220		311	222

Table 3. X ray pikes of sample S₁₀

Phases	Pikes									
	1	2	3	4	5	6	7	8	9	10
M₇C₃			100			102	110			
MC₃		020		201	011	110				
αFe	111	110		200	211	220	210	222		
M₂₃C₆		111		200		220	211		310	222
C	002				110			300		400

Table 4. X ray pikes of S₁₃

3.2. Mechanical testing

The results of surface hardness, toughness, tensile strength and wear resistance tests are summarized in Table 5. The hardness of the FeCr reinforced samples (S₁-S₆) increased by FeCr reinforcement (Figure 6.a). The reason for this increase in hardness can be attributed to the increase in wt% of FeCr reinforcement and the diffusion of dissolved Cr atoms into the matrix. Moreover, the addition of graphite with FeCr particulates increased hardness significantly (Figure 6.b). The reason is thought to be due to formation of pearlite phase in matrix, and as well due to the ledeburite, M₃C₂, and σ phases (Figure 4-Table 3). In addition to the X-ray diffraction, EDS analysis form these phases are taken and it was detected as; the amount of Cr is 6wt.% and 8-12 wt.% in M₃C and ledeburitic structure, respectively. Furthermore, the hardness data of the samples S₇-S₁₀ also showed well agreement with the presence of the phases obtained (Table 3).
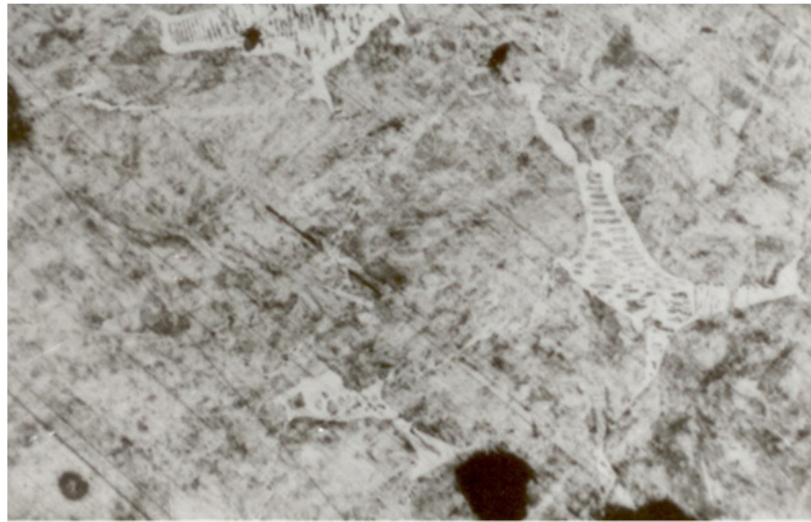
Figure 5. Optical micrographs of the sample S13

|	Composition	Hardness HB	Toughness J Cm²	T Strength MPa	Weight Loss (mg)		
					10 N	20 N	30 N
S1	Fe	55,75	486	27	0,57	0,87	1,12
S2	Fe+1wt%FeCr	64,4	336	24	0,55	0,83	1,09
S3	Fe+3wt%FeCr	72	384	32	0,6	1,93	1,235
S4	Fe+5wt%feCr	77,66	207,5	41,5	0,7	1,023	1,254
S5	Fe+7wt%FeCr	94	48	48	0,95	1,1	1,51
S6	Fe+10wt%FeCr	116	40,95	58,5	1,2	1,4	1,859
S7	Fe+5wt%FeCr+ 0,25wt% Graphite	79	492,64	61,58	0,78	0,87	1,12
S8	Fe+5wt%FeCr+ 0,5wt% Graphite	95	504	72	0,61	0,75	0,98
S9	Fe+5wt%FeCr+ 1wt% Graphite	121,75	420	84	0,57	0,7	0,94
S10	Fe+5wt%FeCr+ 2wt% Graphite	281	311,5	89	0,18	0,27	0,31
S11	Fe+5wt%FeCr+0,5wt%Graphite+%0,5wt%Cu	214	429	78	0,31	0,45	0,5
S12	Fe+5wt%FeCr+0,5wt%Graphite+1wt%Cu	220	346,4	86,6	0,29	0,4	0,45
S13	Fe+5wt%FeCr+0,5wt%Graphite+2wt%Cu	224	241,975	96,79	0,21	0,34	0,4

Table 5. The mean values and error bands of results of surface hardness, toughness and wear resistance tests

The effect of copper supplement with graphite and FeCr particulates on the hardness of the samples was detected for the samples namely S_{11}, S_{12} and S_{13}. The relationship between hardness and wear resistance was given in Figure 6.c as function of Cu concentration. As seen from the figure, Cu supplement increased hardness considerably. The increase in hardness is probably due to the microstructural change, and the reason for formation of martensitic and bainitic structures are due to presence of alloying elements. C, Cr and Cu elements in the structure decrease formation temperature of martensite (Ms) and bainite (Bs) and they provoke formation of these phases [28,29]. It was detected that, copper is present as 0.05-0.25, 1.43-2.87, 1.98-4.94 wt% in martensitic+bainitic zone, respectively, and Cr is detected in the range of 1.98-4.94 wt% Cr in the same samples by EDS analysis. In other
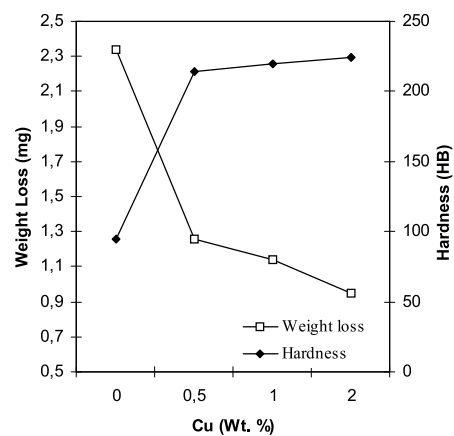
words, the amount of Cr in martensitic and bainitic structures increased with increasing the amount of copper supplement.
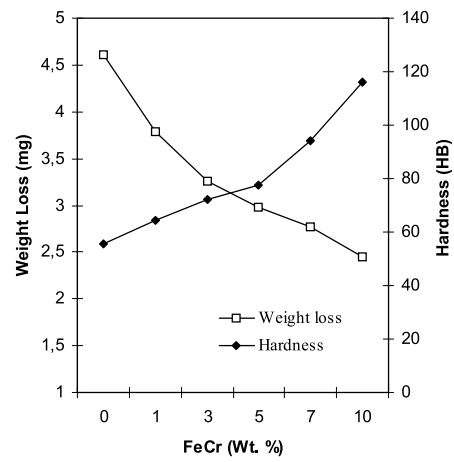
(a)
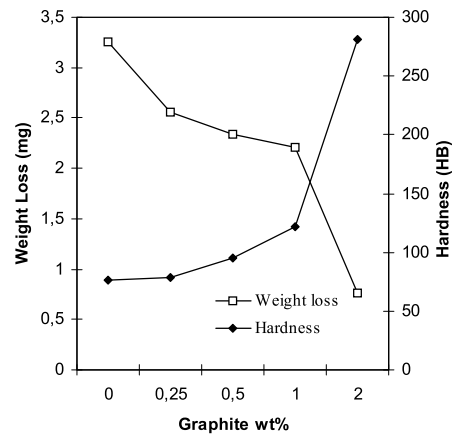
(b)

(c)

Figure 6. The relationship between hardness and weight loss as function of (a) FeCr (b) graphite (c) copper concentration

Reinforcement of the FeCr carbides increased toughness of the samples (S_1-S_6) significantly (Figure 7.a). However, the toughness of the samples having graphite was changed, and an optimum point for the amount of graphite was found. At the beginning, graphite increased toughness, however after 0.5 wt.% graphite additions, the amount of graphite decreased toughness (Figure 7.b). This decrease is attributed to the presence of graphite particles, hard intermetallic phases and the diffusion of Cr into the matrix producing a brittle structure.

The weight loss of the samples S_7, S_8, S_9 and S_{10} decreased with the increase in the amount of graphite. Investigations on microstructure of the samples having graphite supplement in the range 0.25 to 2 wt% (with 5wt% FeCr particulates) have showed that additional phases were formed. Moreover, the increase in the amount of graphite also decreased the size of FeCr particulates. It was conjectured that the decrease of particulate size improved wear resistance. Because, the good bonding between the composite constituents avoids third body abrasion and allow to FeCr particulates to act as load-bearing elements of the composite. Investigations on the toughness of the samples having copper show that copper addition decreased toughness (Figure 7.c), because copper increased the amount of Cr in all of the phases, and provided formation of martensite and bainite phases. Furthermore it increased the diffusion rate and decreased the size of carbides

The change in weight loss vs. load of the samples S_1-S_6 is given in Figure 8.a. For all loads, the highest weight loss obtained for the sample S_6 and the sample S_1 gave the lowest weight loss. Investigations on the microstructure of the sample S_6 show that, the matrix of S_6 was constituted from ductile ferrite phase. Hence, it is conjectured that FeCr particulates were easily pulled out during wear. Also, within craters (*i.e.*, where flakes of material cracked and wore away) FeCr particulates protruded from the surface. Particularly the sample S_{10} has shown the lowest weight loss and a different wear behavior. On the other hand for all loads the wear rate of the samples S_6-S_9 are near to each other (Figure 8.b).

Copper was added to the matrix of the samples S_{11}-S_{13} having FeCr particulates (5wt.%) and graphite (0.5wt.%) together to decrease amount of porosity and friction coefficient. It was observed that copper increased hardness, tensile strength, but decreased toughness and weight loss. The change of weight loss with load has given in Figure 8.c. From the figure it is seen that the effect of load decreased with copper supplement. The relationship between hardness and wear resistance of the samples are given in Figure 9 for 30 N load. The wear tests show that there isn't correlations between wear resistance and hardness for the samples (S_1-S_6) having FeCr reinforcements under abrasive tests over 80 grade abrasives. As the hardness increased, the weight loss increased. On the other hand, addition of graphite to the matrix of the samples (S_7-S_{10}) increased hardness and decreased weight loss, but toughness of the samples didn't changed parallel to the weight loss of the samples. Because, the microstructure of the matrix has been changed by diffusion of carbon atoms into the matrix, and besides shrinkage of carbide particulates have been seen. Furthermore, the Cu supplements have shown that the wear rate of samples S_{11}, S_{12}, S_{13} changed proportionally with surface hardness.
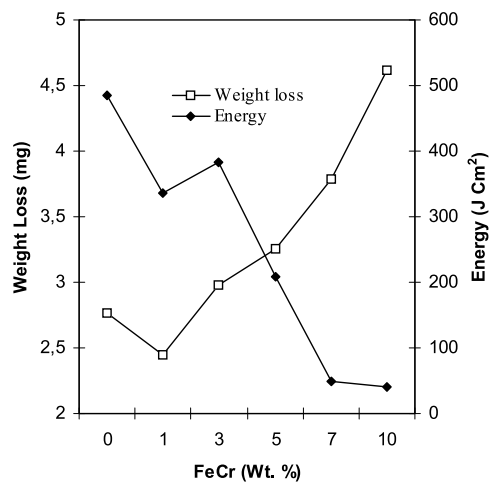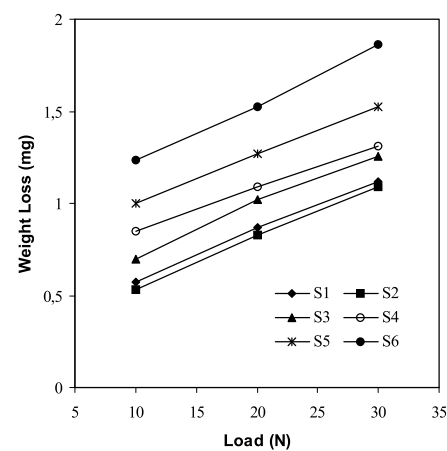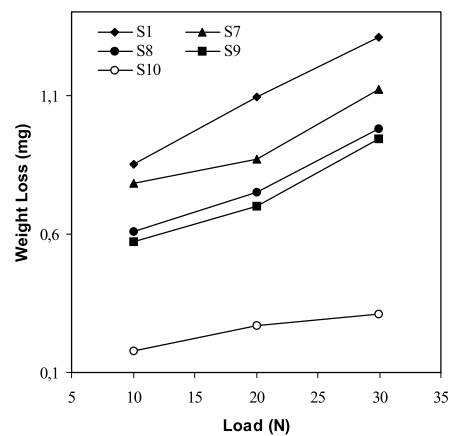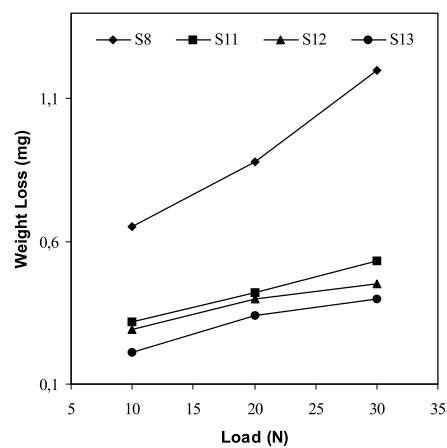
(a)
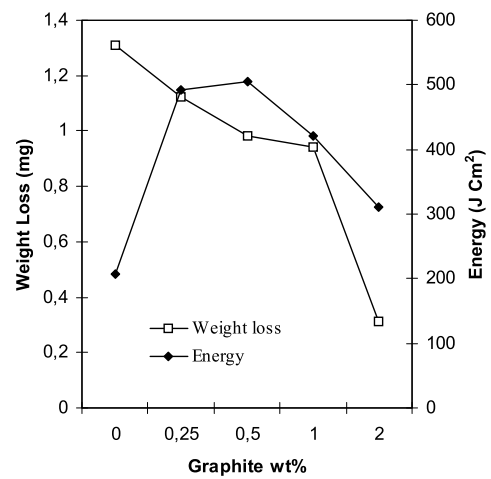
(b)
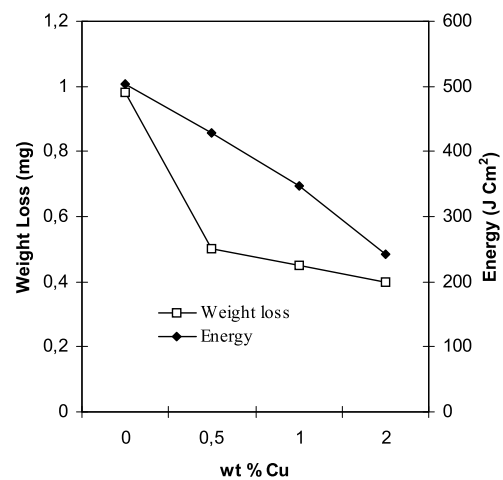
(c)

Figure 7. The relationship between toughness and weight loss as function of (a) FeCr (b) graphite (c) copper concentration

(a)

(b)

(c)

Figure 8. Wear rate vs. load for the samples (a) S_1-S_6 (b) S_7-S_{10} (c) S_{11}-S_{13}

A qualitative difference was found between tracks of Fe/FeCr/graphite-Fe/FeCr/Cu and Fe/FeCr specimens, suggesting less sensitivity to the load of the former. This delay of the load effect can be attributed to the presence of FeCr particulates, size of particulates and

hardness of the matrix, and particulates indicated that they act as load-bearing elements more efficiently than ceramics. Furthermore hard abrasive ceramic reinforcements, such as SiC, have the deleterious effect of wearing the counterface more than the unreinforced material does [30,31]. In addition, as cracks might propagate through the matrix/ceramic reinforcement interface [32,30] pulled out ceramic particles may act as third-body abrasion elements [32] of both specimens and counterfaces, worsening wear behavior of composite/counterface system.
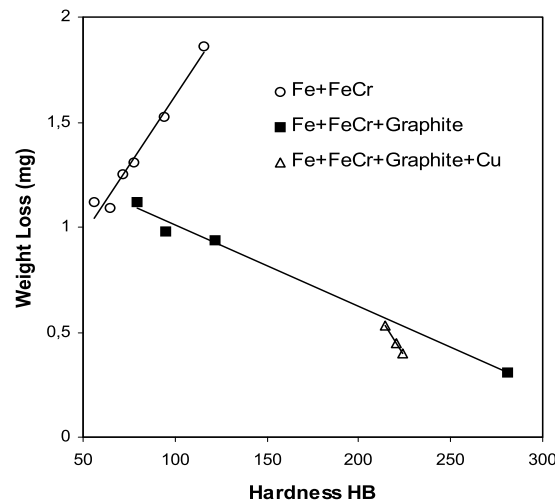
Figure 9. The relationship between hardness and weight loss (30 N load and 80 grade abrasive).

4. Conclusion

The wear tests applied over 80 grade abrasive papers have shown that the weight loss of the MMCs having only FeCr particulates increased with increase of FeCr ratio. However, increase in wt.% of FeCr particulates increased hardness, toughness and yield strength. Graphite supplement with FeCr particulates have formed additional phases, decreased size of FeCr particulates and increased matrix hardness. Hence, weight loss decreased, and increasing graphite amount increased hardness linearly. On the other hand, toughness of the samples having graphite additives decreased after 0.5wt.% graphite. Nevertheless, the wear rate of the samples were changed accordingly to load, but the wear rate of S_{10} didn't changed in a considerable amount with load, and its rate was far low than other samples. Samples with copper additive have shown an increase in hardness, tensile strength with Cu amount. However, toughness was decreased with weight loss. In addition the dependence of the weight loss of the samples with copper to the load decreased with copper addition.

Author details

S.O. Yılmaz[*] and M. Aksoy
Department of Material and Metallurgical Engineering Fırat University Elaziğ, Turkey

[*] Corresponding Author

C. Ozel, H. Pıhtılı and M. Gür

Department of Mecahnaical Engineering Fırat University Elaziğ, Turkey

5. References

[1] Metal powder Industries Federation: "*Powder metallurgy Equipment Manuel*" New York, 1968.

[2] D.L. McDanels, *Metall. Trans.*16A (1985) 1105

[3] C. Millliere and M. Suery, *J. Mater.Sci.* 34-36 (1988) 41.

[4] C.G.Levi, G.J. Abbascian and R. Mehrabian, *Metall, Trans.*, 9A (1978) 697.

[5] A. Mortensen and I. Jin, *Int. Mater. Rev.*, 37 (3) (1992) 101.

[6] F.M. Hosking, F.F. Portillo, R. Wunderlin and R. Mehrabin, *J. Mater.Sci.,* 17 (1982) 477.

[7] Ovingsbo, Proc. Conf. Wear of Materials, ASME, New York, 1979, p.620.

[8] K.H. Zum Gahr, Microstructure and Wear of Materials, Elsevier, Amsterdam, 1987, pp.132-495.

[9] D.Godfrey, Diagnosis of Wear Mechanism, in: M.B. Peterson, W.O. Winer (Eds.), Wear Control Handbook, ASME, New York, 1980, pp. 283-312.

[10] Y. Wang, T.C. Lei and C.Q. Gao, *Tribol. Int.*, 23(1) (1980) 47-53.

[11] D.A. Rigney and W.A. Glaeser, Wear of Materials, ASME, New York. 1977, pp. 41-46.

[12] T.L. Ho, M.B. Peterson. F.F. Ling, *Wear* 30 (1974) 73-91.

[13] T.L. Ho, , M.B. Peterson.. *Wear* 43 (1977) 199-210.

[14] T.L. Ho, in: W.A. Glasser (E.), Wear of Materials, American Society of Mechanical engineers, New york, 1977, pp.70-76.

[15] R. Munro, International Congress and Exposition, Detroit, MI, 28 February-4 march 1983, SAE Tech Paper 830067.

[16] J. Dinwoodie, E. Moore, C.A.J. Langman, W.R. Symes Jr, in: W.C. Harrigan. J. Strife, J. Metallurgical Society of AIME. Metalurgiacal Society of AIME, Warrendale, P.A. 1985, pp. 671-685.

[17] H.L. Lee, W.H. Lu and S.L.I. Chan, Chin., *J. Mater.Sci.*, 24 (1) (1992) 40-52

[18] D.L. Erich, Int. *J. Powder Metal.*, 23 (1) (1987) 45-54

[19] S.V. Prasad and P.K. Rohatgi, *J. Met. Sci.*, 39 (11) (1987) 22-26

[20] K.J. Bhansali and R. mehrabian, *J. Met. Sci.*, 34 (9) (1982) 30-34

[21] F.M. Hosking, F. F. Portillo, R. Wunderlin and R. mehrabian, *J. Mater. Sci.*, 17 (1982) 477-498.

[22] M.K. Surappa, S. V. Prasad and P.K. Rohatgi, *Wear*, 77 (1982) 295-302.

[23] P.R. Gibson, A.J. Cleg and A. A. Das, *Wear*, 95 (1984) 193-198.

[24] S.J. Lin and K.S. Liu, *Wear*, 121 (1988) 1-14.

[25] Y.M. Pan, M.E. Fine and H.S. Cheng, *Scr. Metal.*, 24 (1990) 1341-1345.

[26] A.K. Jha, S.V.Pprasad and G.S. Upadhyaya, *Wea*r, 133 (1989) 163-172.

[27] E.A Brandes, Metals Reference Book. 6 th edition. Butterworths, London. (1983).

[28] A. Wang and H.J. Rack. *Mater. Sci. Eng.*, (1991), vol. A147, pp.211-24

[29] I.M. Hutchings: *Mater. Sci. Eng.*, (1994), A184, pp. 185-95.

[30] A.T. Alpas and J. Zhang: *Metall. Mater. Trans*. A, (1994), vol. 184, pp. 187-92.

[31] W.Ames and A.T. Alpas: *Metall. Mater. Trans*. A, (1995), vol. 26A, pp. 85-98

[32] P.L. Ratnaparkhi and H.J. Rack: *Mater. Sci. Eng.*, (1990), vol. A129, pp. 11-19.