Study On Wear Resisting Properties of Deoxidized High Grade Cast Iron. I : On Wear of Flake Graphite Cast Iron

Study on Wear Resisting Properties of Deoxidized High Grade Cast Iron. I

On Wear of Flake Graphite Cast Iron*

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(Received March 3, 1960)

Synopsis

Comparison was made between wear resisting properties of deoxidized high grade cast iron and those of other cast irons, and the following results were obtained:

Deoxidized high grade cast irons have superior properties in wear resistivity by its strong, tough qualities, and graphite carbon. The reason is that the pearlitic matrix has strong and tough qualities, wormy flake graphite or spheroidal graphite being created by the deoxidation. Eutectic graphite cast iron does not prove wear resistivity under heavy load.

I. Introduction

In recent years the manufacturing of high grade cast iron has been increased in Japan. Along with improvements in the mechanical properties, studies on the wear resistance and surface hardening have been carried out. Graphite in the conventional industrial cast iron is coarse, irregular flaky, or eutectic graphite, and its matrix is mainly pearlite. In this case, the wear resistance is not always good. In general, for the purpose of improving wear resistance, there is a trend to harden the matrix by increasing Mn and P contents or adding special alloying element, such as Cr, Ni, Mo or W. Acicular bainitic cast iron is a typical one. As high grade cast irons having good wear resistance, there are fine flake graphite cast iron and spheroidal graphite cast iron, and of which wear resistance is being studied.

One of the present authors revealed that wormy flake (fine flake) graphite cast iron could be manufactured in an electric arc furnace without adding special alloying elements only controlling contained oxygen content from the fundamental studies about relationship between cast iron and its oxygen contents(1). There have been developed electric arc furnace high grade cast irons on the similar idea. By many studies on the mechanical properties, the factors for improving wear resistance in ordinary cast iron can be considered to be as follows: (1) the shape of graphite: eutectic → coarse flaky → wormy or spheroidal; (2) the distribution state of graphite: entirely uniform distribution; (3) the amount of gra-

* The 977th report of the Research Institute for Iron, Steel and Other Metals.

(1) M. Homma, J. Japan Foundrymen's Society, **31**, (1959), 477.

phite: relatively higher C content is desirable rather than low C content because of graphite lubricant agent; (4) matrix and existence of carbide: ferrite → pearlite → sorbitic pearlite → bainite or martensite; and (5) existence of steadite. In the present study, which is to be followed by the investigations on the wear phenomenon and wear mechanism, the comparison of wear resistance among high grade cast iron without alloying elements, having wormy (fine) graphite structure and ordinary cast iron and pearlitic cast iron, the relationship between the structure of cast iron and the wear amount, and the relationship to wear among combination of various cast irons were investigated.

II. Experiment by Kaken-type wear tester

1. Specimens and experimental method

A schematic diagram of Kaken-type dry wear tester is shown in Fig. 1. In this tester a specimen is contacted on to outer circle of a rotary drum, the velocity of which is adjustable. The dimension of the specimen was 5 mm$\phi \times$ 10 mm, which can be chucked to a holder. The specimens for wear test were of small dimension cut from tensile test specimens. The finishing accuracy of the rotary drum and small specimens were 3 to 6 S (surface finishing grade). After adjusting the contact btween specimens and drum, the measurement of wear started in the stationary condition. The chemical composition, structure and mechanical properties of high grade cast iron by reducing refining with electric arc furnace and ordinary cast iron in this experiment are shown in Table 1. The symbols of oxygen content are given in Fig. 2, which is a graphical representation of relationship between oxygen content and the various properties of cast iron, especially, tensile strength (as-cast) and heredity of cast irons, it was partly reported by the present authors(1), but the details will be shown in the future. In ordinary cast iron (symbol O) the effects of graphite as a lubricant agent and steadite were investigated by increasing C and P contents. In other ordinary cast iron specimens except RE-B, P content is less than 0.05 per cent and the addition of Cr is also small. It is a characteristic of spheroidal graphite cast steel(2) (SN-A, B) that it shows the mechanical properties similar to spheroidal graphite cast iron by heat treatment.

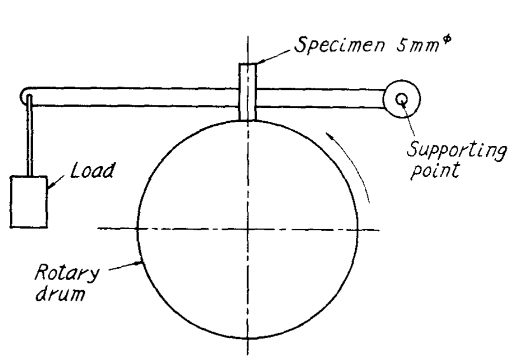

Fig. 1. Schematic diagram of Kaken-type wear testing machine.

2. Results of wear tests and discussion

8.1 and 13.3 kg/cm^2 of contact load are heavy in this kind of wear tester. The results obtained are shown in Figs. 3 and 4. In Fig. 3 a drum made of soft steel (0.15% C) was used for a standard specimen. The wear of oxidized eutectic

(2) M. Homma, J. Japan, Foundrymen's Society, **31** (1959), 9.

Table 1. Chemical composition and mechanical properties of specimens.

Mark of specimens	Degree of refining	Variety of Cast iron	Chemical composition (%) C	Si	Mn	P	S	Cr	N	Micro structure	Tensile strength kg/mm²	Elongation %	Hardness Rockwell
O	Ⅰ～Ⅱ	Ordinary flake graphite cast iron	3.54	1.79	0.48	0.310	0.098	0.024	0.033	Coarse flake gr. pearlite, steadite	16.9	—	R_B 79.7
OC-1	Ⅱ～Ⅲ	Oxidized eutectic graphite cast iron	2.46	2.83	0.26	0.046	0.010	tr	0.009	Eutectic gr. (ab 30%) fine flake gr. pearlite	21.9	—	R_C 5.0
OC-2	Ⅱ～Ⅲ	〃 〃	3.43	1.46	0.26	0.032	0.030	tr	0.023	Eutectic gr. pearlite ferrite (ab 3%)	25.2	—	R_C 9.4
SWF-A	Ⅱ′～Ⅲ′	Wormy flake (fine flake) graphite high grade cast iron	2.85	1.96	0.24	0.033	0.018	0.042	0.007	Wormy flake gr. pearlite	35.3	—	R_C 14.5
SWF-B	Ⅱ′～Ⅲ′	〃 〃	2.78	1.17	0.31	0.023	0.004	0.010	0.013	〃 〃	36.6	—	R_C 15.0
RE-A	Ⅲ′～Ⅳ′	Reduced eutectic graphite cast iron	2.81	2.39	0.27	0.024	0.015	0.013	0.009	Eutectic gr. pearlite	28.8	—	R_C 15.6
RE-B	Ⅲ′～Ⅳ	〃 〃	3.27	1.41	0.37	0.084	0.007	0.015	0.011	Eutectic gr. pearlite ferrite (ab 5%)	24.5	—	R_C 14.1
SN-A	Ⅳ′	Spheroidal graphite cast steel	1.50	1.97	0.32	0.028	0.004	0.012	0.014	Spheroidal gr. pearlite	59.2	1.0	R_C 30.5
SN-B	Ⅳ′	〃 〃	1.27	2.97	0.31	0.028	0.017	0.025	0.014	〃 〃	75.4	1.0	R_C 29.5
SSG	Ⅳ′	Semi spheroidal graphite cast iron	3.63	2.71	0.27	0.024	0.005	0.010	0.007	S.G., Quasi S.G. pearlite, ferrite (ab 50%)	45.5	—	R_C 7.6
		Ordinary cast iron for liner	3.61	2.05	0.79	0.139	0.018	—	—	Coarse flake gr. pearlite	—	—	R_B 97.3

graphite cast iron (RE-A, B) was markedly large. In general, it was found in this experiment that eutectic graphite cast iron was easy to wear independently of the oxygen content in cast iron. This trend, however, is expected to be changed by the weight of contact load. Compared with ordinary cast iron (O) containing large amounts of C and P, SWF-A, SN-A and SSG showed a trend of larger wear. This seems to be influenced by the fact that the contacting drum made of soft steel contains no lubricant. Fig. 4 is the result obtained by using a drum made of ordinary cast iron for liner. The wear of OC-1, 2, RE-A, B, and SSG was large. SWF-A, B and SN-A, B showed better wear resistance than ordinary cast iron (O). In the case

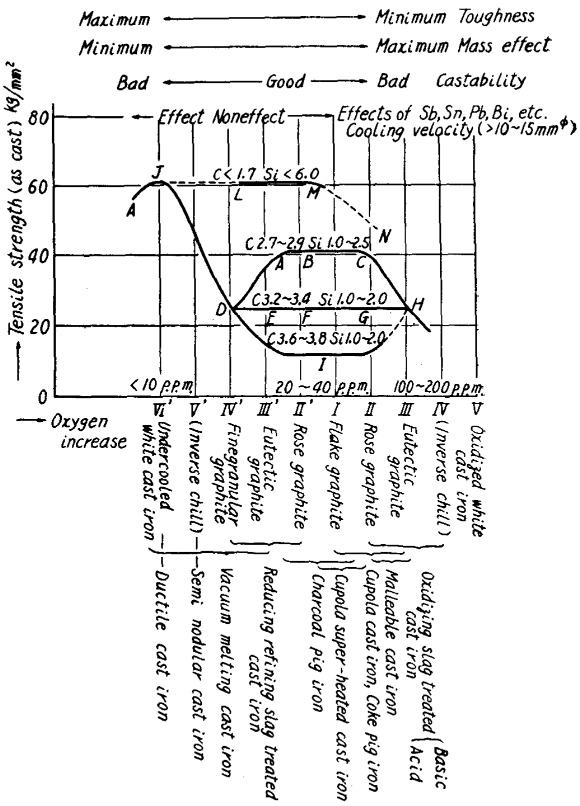

Fig. 2. Relationship between various properties of cast iron and its oxygen contents. (M. Homma).

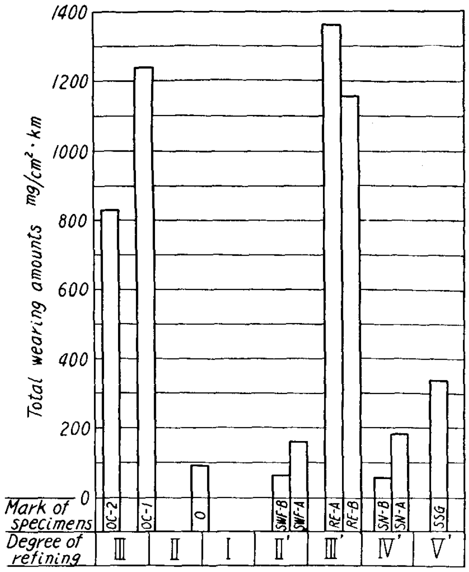

Fig. 3. Relationship between variety of cast iron and its wearing amounts. (A) Dry abrasion, contact load 13.3 kg/cm², friction speed 8.1 m/sec, friction distance 2 km, other material; soft steel drum 140 m/mϕ.

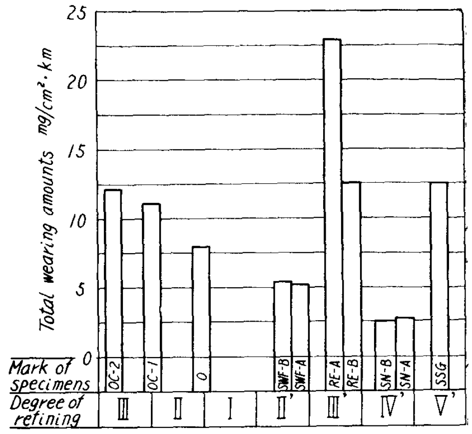

Fig. 4. Relationsyip between variety of cast iron and its wearing amounts. (B) Dry abrasion, contact load 8.1 kg/cm², friction speed 6.8m/sec, friction distance 24.6 km, Other material: Liner cast iron drum 120 m/mϕ.

of soft steel drum, SSG cast iron itself is of high C content, so that graphite acts as lubricant and reduces the effect of ferrite matrix. In the case of cast iron drum with pearlitic structure containing comparatively high amount of P, large wear can be considered due to the remarkable effect of ferrite matrix.

Next, a drum made of ordinary cast iron was used for liner as partner under low load of contact pressure 3.0 kg/cm^2, and the results obtained are shown in Fig. 5. In this case the wear of all specimens was similar to one another and no difference was shown between materials except a few anomalous cases. There was little difference of wear resistance between high grade cast iron and eutectic (reduced) graphite cast iron. Only OC-1 showed anomalous wear. Further investigations are going to be carried out on varying the drum velocity under the constant contact pressure, or on the contrary on varying the contact pressure at constant velocity.

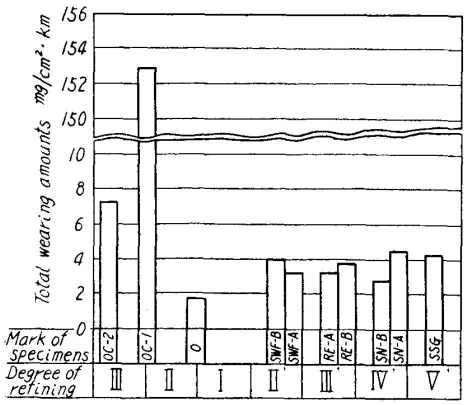

Fig. 5. Relationship between variety of cast iron and its wearing amounts. (C) Dry abrasion, contact load 3.0 kg/cm^2, friction speed 1.3 m/sec, friction distance 10.0 km, Other material: Liner cast iron drum 110 m/mϕ.

It should be noted that marked difference will occur according as whether the materials of the contacting drum, is made of soft steel or cast iron, that is, whether it contains graphite lubricant or not.

III. Experiment by Amsler-type wear tester

1. Specimens and experimental method

The dimension of specimens for Amsler-type wear tester is shown in Fig. 6. The specimens were machined from green sand mould cast 50 mm in diameter to disc shape 40 mm in diameter, and 10 mm in thickness with a hole 16 mm in diameter, and the rolling test together with sliding was carried out. The finishing accuracy was 3 to 6 S. Rotation velocity of the upper specimen was 166 r.p.m., and that of the lower one was 185 r.p.m., sliding was 10 per cent, and sliding velocity was about 0.04 m/sec. The wear tests were carried out in dry and oil lubricating (machine oil was used) conditions on the upper and lower drum of the combinations of the same quality and of different quality. The fact that the velocity of the lower specimen is faster than that of the upper one, seems to influence the wear on different quality ones, but in each combination the result obtained was different and the common effect was hardly observed. The

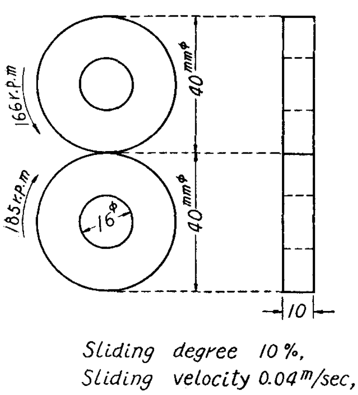

Fig. 6. Specimens' size and testing condition for Amslar-type.

Table 2. Chemical composition and mechanical properties of specimens.

Mark of specimens	Variety of Cast iron	Chemical composition (%)								Micro structure	Tensile strength kg/mm²	Elongation %	Hardness	
		T.C	G.C	C.C	Si	Mn	P	S	Cr				B.H.N.	Rockwell
O	Ordinary flake graphite cast iron	3.54	3.13	0.41	1.79	0.48	0.310	0.098	0.024	Coarse flake gr. pearlite, steadite	16.9	—	148	R_B 79.7
OC	Oxidized eutectic graphite cast iron	3.43	2.83	0.60	1.46	0.26	0.032	0.030	tr	Eutectic gr. pearlite ferrite (ab 3%)	25.2	—	179	R_C 5.0
M-G	High grade cast iron by Ca-Si treated	2.92	2.25	0.67	1.08	0.48	0.084	0.112	—	Fine flake gr. pearlite	—	—	230	R_C 22.0
SWF-A	Wormy flake graphite high grade cast iron	2.81	2.11	0.70	1.04	0.38	0.033	0.005	0.010	Wormy flake gr. pearlite	36.0	—	240	R_C 14.5
SWF-B	〃 〃	2.78	2.12	0.66	1.16	0.42	0.017	0.005	0.038	〃 〃	38.9	—	211	R_C 15.0
SWF-C	〃 〃	2.93	2.32	0.61	1.34	0.67	0.109	0.018	0.058	〃 〃	35.0	—	219	R_C 22.1
SWF-D	〃 〃	2.53	2.31	0.22	1.33	0.23	0.088	0.023	—	〃 〃	35.0	—	213	R_C 19.4
SWF-E	〃 〃	3.13	2.95	0.78	1.31	0.41	0.100	0.070	0.029	Fine flake gr. pearlite	32.5	—	190	R_C 9.4
SN-A	Shperoidal graphite cast steel	1.58	1.10	0.48	2.02	0.33	0.073	0.016	tr	Spheroidal gr. pearlite	61.8	1.0	296	R_C 30.5

chemical composition, structure, and mechanical properties of specimens used are shown in Table 2. The tensile strength was measured by the test specimens machined to JIS 8C except SN-A which was measured by JIS 4 specimen as-cast. The wear resistance of high grade cast iron for general construction manufactured by the inoculation of Ca-Si alloy and melted in a cupola furnace at high temperature was compared with wormy flake (fine flake) cast iron refined in an electric arc furnace.

2. Results of wear tests and discussion

(i) The dry wear test on the upper and lower specimens of the same quality

The results obtained in the upper and lower specimens of the same quality are shown in Fig. 7 (under contact load 25 kg) and Fig. 8 (under contact load 50 kg). In these examples, it is considered that the presence of lubricant plays a more definite role in the wear than materials so that there was found a trend that the wear decreased with the increase in carbon content in cast iron. As shown in Fig. 8, however, it is to be noted that the wear decreased more greatly from about 140 thousand revolutions in SWF-C (2.93% C) and SWF-D (2.53% C) than in M-G (2.92%) which was Ca-Si inoculated cupola high grade cast iron. The specimen SWF-E (3.13%) whose carbon content was higher than those mentioned above showed the lower hardness than that of lower carbon content, but its wear became smaller and it was found that these properties were influenced markedly by the carbon content in this case.

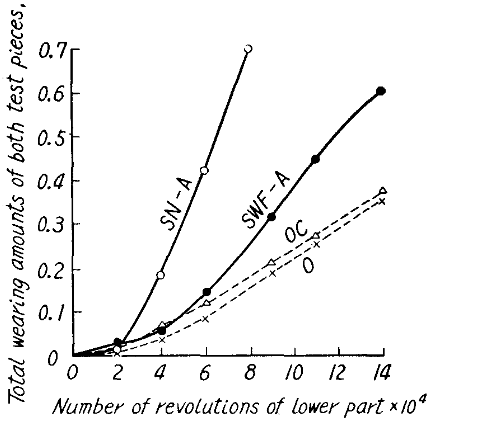

Fig. 7. Amslar-type dry abrasion. Upper and lower materials of identical quality. Contact load 25 kg.

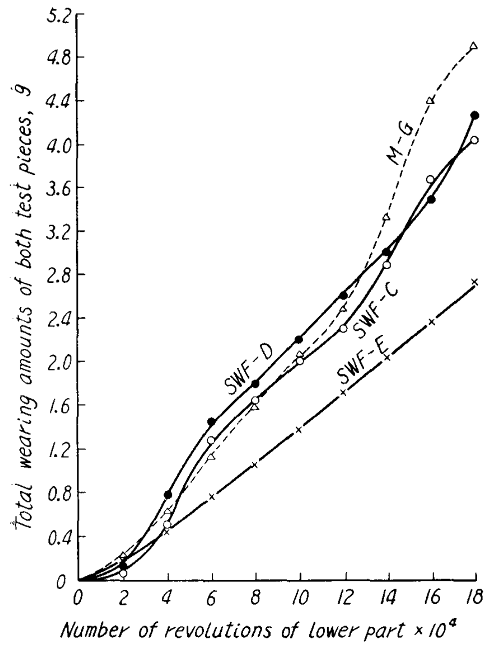

Fig. 8. Amslar-type dry abrasion. Upper and lower materials of identical quality. Contact load 50 kg.

In experiment (i) from viewpoint of graphite lubrication, it is important to increase relatively carbon content without weakening the materials to keep the balance between the toughness of matrix and graphite.

(ii) The dry wear test on the upper and lower specimens of different quality

Fig. 9 shows the result of wear tests carried out under a contact load of 50 kg with high carbon ordinary cast iron as the upper specimen and spheroidal graphite cast steel and high grade cast iron SN-A, SWF-B as the lower specimen. The wear of upper specimens was larger than that of lower specimens in all cases. Fig. 10 shows the result of the wear tests carried out under 25 kg of contact load with SWF-E and SWF-B, and vice versa. In

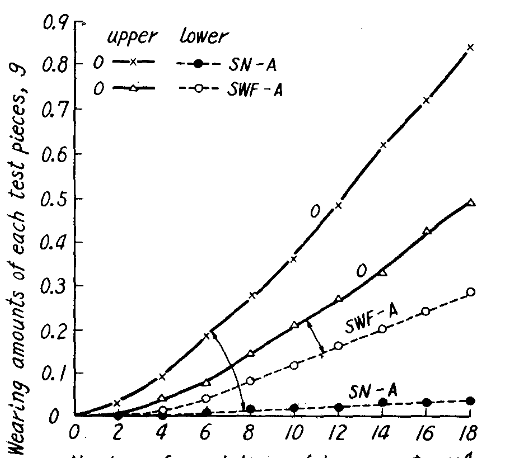

Fig. 9. Amslar-type dry abrasion. Upper and lower materials of different quality. Contact load 50 kg.

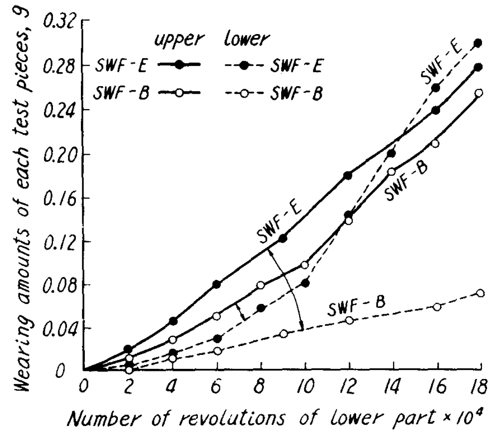

Fig. 10. Amslar-type dry abrasion. Upper and lower materials of different quality. Contact load 25 kg.

both cases the specimen of high grade cast iron containing 2.8 per cent C showed the better wear resistance. The toughness of material seems to correspond to its wear resistance. A good wear resistance was observed in the partner material containing high carbon or high carbon and phosphorous.

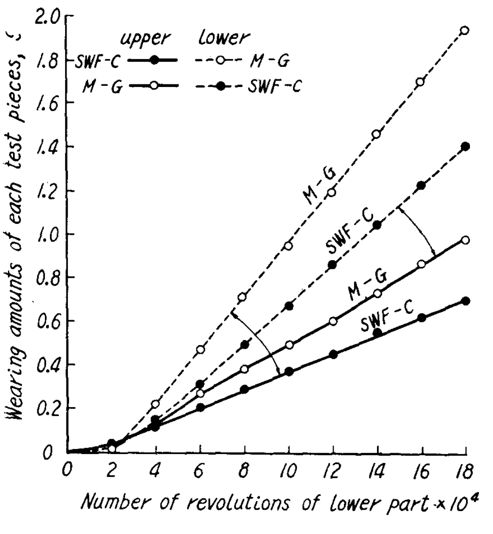

Fig. 11. Amslar-type dry abrasion. Upper and lower materials of different quality. Contact load 50 kg.

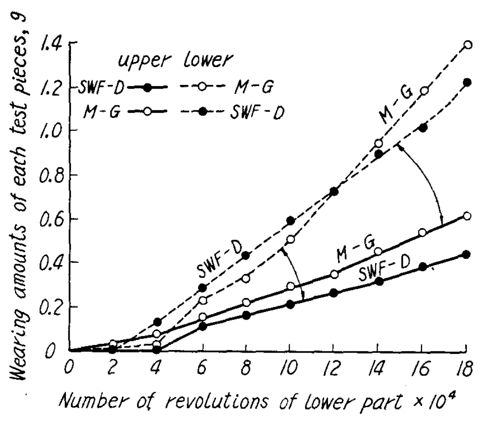

Fig. 12. Amslar-type dry abrasion. Upper and lower materials of different quality. Contact load 30 kg.

In Figs. 11 and 12 are shown the results of wear tests carried out under 50 kg and 30 kg of contact load respectively with Ca-Si inoculated high grade cast iron M-G melted in a cupola at high temperature, and two kinds of wormy flake graphite cast iron SWF-C and SWF-D melted in electric arc furnace, and vice versa. In these cases, there was a trend that the wear of the upper specimens was smaller than that of lower ones. The total wear amount of both specimens was 2.894 g to M-G, 2.095 g to SWF-C in Fig. 11, and 2.006 g to M-G and 1.672 g to SWF-D in Fig. 12 respectively in the specimens of same quality. Therefore, the high grade cast iron melted in electric arc furnace showed a smaller amount of total wear and better characteristics than others.

Wormy flake graphite cast iron showed a trend of relatively larger wear in the primary stage of abrasion and a good wear resistance under the stationary wear condition (Figs. 10, 12, 13 and 16). This can be explained on the ground that this material is easy to fit with the partner material even in the primary stage of wear.

(iii) The oil lubricating wear test on the upper and lower specimens of the same quality

Fig. 13 shows the result obtained by the oil lubricating wear test under 100 kg of contact load. Wormy graphite high grade cast iron (SWF-A) and spheroidal graphite cast steel (SN-A) have better wear resistance than ordinary cast iron (OC and O). Further, a similar test under 200 kg of contact load was carried out and the result obtained is shown in Fig. 14. With increase of the

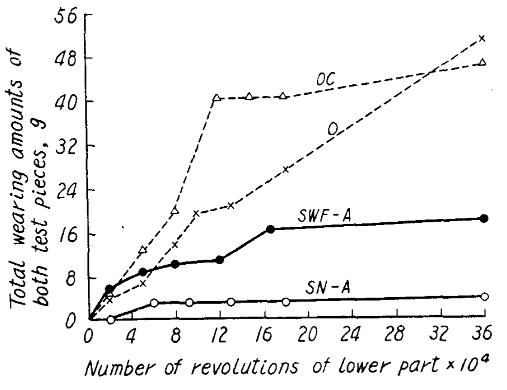

Fig. 13. Amsler-type oil abrasion. Upper and lower materials of identical quality. Contact load 100 kg.

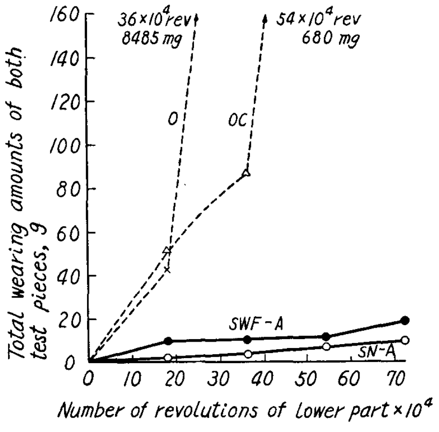

Fig. 14. Amsler-type oil abrasion. Upper and lower materials of identical quality. Contact load 200 kg.

load, the effect of materials became larger and the difference of wear resistance by materials became marked. The wear of SN-A and SWF-A under 200 kg load after 720 thousand revolutions was very small and similar to that under 100 kg load. On the contrary, the trend of breaking wear appeared from 180 thousand and 360 thousand revolutions in the case of an ordinary cast iron and OC specimen respectively.

The result of comparison between the high grade cast iron inoculated with Ca-Si and melted in a cupola at high temperature and cast iron melted in an electric arc furnace under 150 kg of contact load is shown in Fig. 15. The wear of M-G was small until 240 thousand revolutions, but above that progressively increased. After all, the wear of SWF-D (2.53%C) was minimum and there was a trend that the wear becomes smaller in order of decreasing carbon content in the specimens. It is to be noted that the wear resistance of SWF-C, D was better than M-G in spite of lower hardness.

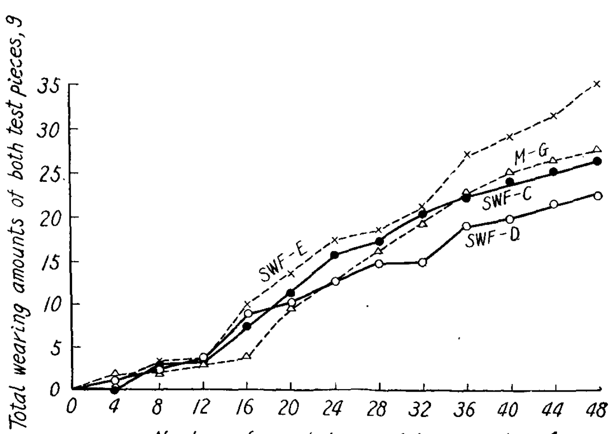

Fig. 15. Amsler-type oil abrasion. Upper and lower materials of identical quality. Contact load 150 kg.

(iv) The oil lubricating wear test on the upper and lower specimens of different quality

The result obtained in the oil lubricating wear test on the upper and lower specimens of different quality under 100 kg of contact load is shown in Fig. 16. In the combination of ordinary cast iron (O) and SWF-A, the primary wear of SWF-A was a little larger but the wear became smaller gradually. But this trend was not observed in the combination of O and SN-A specimens.

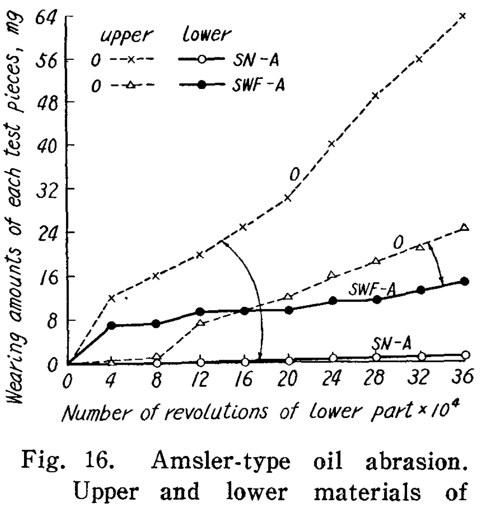

Fig. 16. Amsler-type oil abrasion. Upper and lower materials of different quality. Contact load 100 kg.

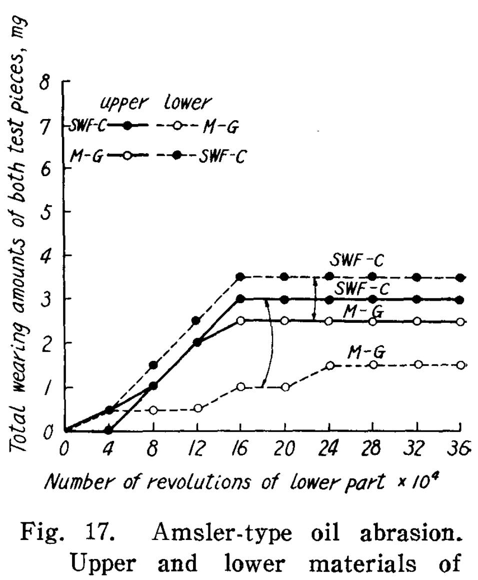

Fig. 17. Amsler-type oil abrasion. Upper and lower materials of different quality. Contact load 150 kg.

The result of wear test on the high grade cast iron inoculated with Ca-Si and melted in a cupola furnace at high temperature in combination with SWF-C is shown in Fig. 17. In this case the wear was remarkably small compared with that of the upper and lower specimens of the same quality in combination with oil lubricant. There was no extreme difference in the wear amount between upper and lower specimens and a good trend was observed as the combination wear.

Summary

We used mainly wormy graphite high grade cast iron containing 2.5~3.0 per cent carbon refined in an electric arc furnace, to which various cast irons were combined, and the dry and oil lubricating wear tests on the same materials and different materials in combination were carried out and the following results were obtained.

In the wear of cast iron, from viewpoint of graphite lubricant, it is important to increase carbon content without making the materials brittle and especially in the combination of specimens of the same quality the dry wear resistance became better. In the presence of graphite or oil lubricant, high grade cast iron showed remarkable wear resistance. The principal reasons for them will be as follows: pearlite structure of matrix is strengthened by deoxidation and the shape of graphite becomes wormy and spheroidal by deoxidation; the solid nonmetallic impurities in the matrix decreases by deoxidation (or desulfurization). Further consideration, however, will be necessary for the understanding of the complex wear phenomenon. On the relationship between high strength of matrix pearlite and deoxidation, further investigation will be necessary. The deoxidation or reduced eutectic graphite cast iron showed no wear resistance under heavy load.

Acknowledgement

The authors extend their thanks to the Congress of Directors of Japanese National University Institutes for the grant of its Fund of Study on Wear.