Wear Resisting Properties of Cast Irons Having Different Shapes of Graphite

Wear Resisting Properties of Cast Irons Having Different Shapes of Graphite*

Yoshihiko ABE

The Research Institute for Iron, Steel and Other Metals

(Received January 14, 1963)

Synopsis

The wear resisting properties of cast irons having different shapes of graphite have been studied on dry wearing without lubricant, by using Fukao-type dry wear tester. It was found that the specimens consisting of ferrite matrix are remarkably less wear resistive in comparison with that of pearlite matrix, and that the wearing amounts increase with the order of shapes of wormy flake, small nodular and eutectic graphite.

I. Introduction

In this research, the wearing properties of cast irons having various shapes of graphite and matrices were studied by using the nodular graphite cast steel as the opposite specimen on wearing tester. The nodular graphite steel is the hyper-eutectoid steel containing nodular graphite, and various properties of this steel were clarified originally by this Research Institute(1).

On wear resisting properties of various cast irons, many investigations have been reported with remarkably different results, because of different combinations of wearing specimens and different wearing conditions. In this paper the wearing process of various cast irons has been studied, taking into consideration the following items:

1. The effects of graphite shapes on the surface hardness, roughness and surface degenerative layer, connecting with the increase of running distance.
2. The effects of graphite shapes and matrices on wearing amounts.

II. Experimental method

1. The experimental conditions

Experiment is carried out by improved Fukao-type dry wear tester, which is capable of weighing the wearing amounts of either the upper or the lower specimen(2). The dimension of the upper specimen is 5mm×5mm×25mm and the dimension of the lower ring specimen is 40 mm (inside diameter)×60 mm (outside diameter)× 11 mm (thickness).

Before wear tests the roughness on the contacting surface of the upper and

---

* The 1078th report of the Research Institute for Iron, Steel and Other Metals.

(1) M. Homma, Y. Abe, H. Meguro and A. Minato, Sci. Rep. RITU, **A 12** (1960), 201.

(2) Y. Abe, Sci. Rep. RITU, **A 14** (1962), 191.

the lower specimen was mechanically finished to 1.5 S (under 1.1μ). Wear tests were carried out under the contact load of 5kgs per square centi-meter. The peripheral velocity of the lower specimen was 3.05 and 4.86 meter per second. In this experiment, wearing condition was similar to the relation between the piston ring and the cylinder of the engine of an automobile and a vessel(3).

The roughness on the wearing surface was measured by the transverse magnification ($\times$5000) and longitudinal magnification ($\times$100) with Kosaka-type instrument for surface roughness, and the roughness of the orthogonal direction against the revolution of the lower specimen was recorded at the running distance of 0, 10, 20, 50, 100 and 400 km respectively (the recording distance on the specimen was 1.5 mm). The hardness on wearing surface was measured by the load 50g with micro-hardness tester.

2. Chemical compositions and mechanical properties

The lower specimens were of nodular graphite cast steel with normalizing

Table 1. Chemical composition and mechanical properties of specimens.

Matrix		Mark	Chemical composition (%)								Mechanical properties		Remark
			T. C	G. C	Si	Mn	P	S	Cr	Ti	Tensile strength kg/mm²	Hardness R_B	
Upper specimen	Pearlite	P-1	3.46	2.59	1.96	0.37	0.40	0.055			15.9	81.8	Ordinary Cast Iron
Upper specimen	Pearlite	P-2	3.23	2.11	2.16	0.30	0.073	0.076			32.0	97.6	Flake Graphite Cast Iron
Upper specimen	Pearlite	P-3	2.80	2.26	1.81	0.35	0.17	0.047			36.9	92.7	Wormy Flake Graphite Cast Iron
Upper specimen	Pearlite	P-4	3.10	2.66	3.63	0.30	0.024	0.009				103.0	Ductile Cast Iron
Upper specimen	Pearlite	P-5	3.16	2.60	2.25	0.46	0.092	0.009	0.119	0.168		93.4	Eutectic Graphite Cast Iron
Upper specimen	Ferrite	F-6	2.22	2.02	1.28	0.42	0.043	0.095			37.8	71.2	Black Heart Malleable Cast Iron
Upper specimen	Ferrite	F-7	1.52	1.47	2.13	0.83	0.014	0.25			42.2	78.6	Nodular Graphite Cast Steel
Upper specimen	Ferrite	F-8	3.10	3.00	3.63	0.30	0.024	0.009				87.5	Ductile Cast Iron
Under specimen	Pearlite	A	1.52	0.76	2.13	0.83	0.014	0.25			86.4	Rc 34.2	Nodular Graphite Cast Steel

(3) H. Lees, Wear, **2** (1958), 273: A. Seifert, Wear, **3** (1960), 426.

structure and the upper specimens were of various cast irons. Chemical compositions, mechanical properties and microstructures are as shown in Table 1*. A–1~5 and A–6~8 of the lower specimen combined with P–1~5 of pearlite matrix and F–6~8 of ferrite matrix of the upper specimen containing different graphite shape.

III. Experimental results and considerations

1. Wear surface

After wear tests the surface roughnesses on the upper and the lower specimens didn't reach the flat plane, similar to the previous paper(1). The surface roughness was influenced more severely by matrix than by graphite shape, and could be classified by matrix into two types, namely, ferrite and pearlite, regardless of peripheral velocity of the lower specimen.

(i) Pearlite type

The surface roughnesses on pearlite matrix could be classified into three types A, B and D, as shown in Fig. 1, and C type curve(1) could not be seen in the present

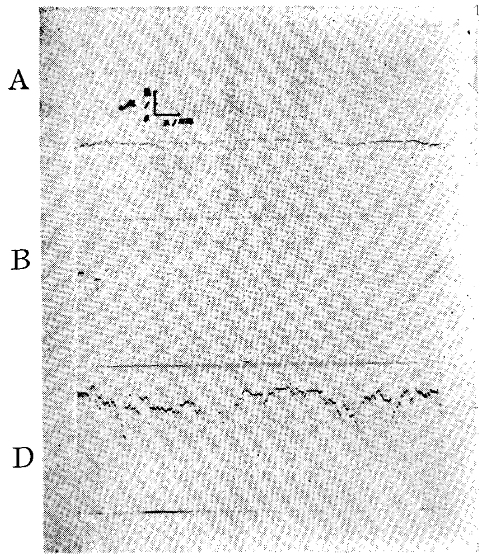


Fig. 1. Pearlite type curve of surface roughness.

experiment. P–1 of the upper specimen of coarse flake graphite shows A type curve. Even though running distance increased, the variation of the roughness of P–1 could not be observed. With the variation of graphite shape from flake to eutectic, the changes in roughness of the specimen from P-1 to P-4 were characterized by the increase of undulation within 10km of running distance; for example, P-4 of specimen had B type curve and P-5 of specimen had D type curve. With further increase of running distance, P–2~4 of the specimen had A type curve and P–5 of eutectic graphite had the mixed curve of B and D. On the other hand, the roughnesses of

* P-1, 2, 3 and 5 (as cast), P–4 (850°C, 2hr-air cool), F–6, 7 and 8 (after malleablizing treatment).

the lower specimens were similar to those of the corresponding upper specimens.

On the contacting surface, P–1～5 of the upper specimen and A–1～5 of the lower specimen were composed of the mixed area of greyish part caused by oxide and lustrous part caused by metallic surface. It was difficult to recognize any difference between them.

(ii) Ferrite type

Compared with those of pearlite matrix, the roughness of the upper specimens consisting of ferrite matrix are to the extremely roughened state, together with those of lower specimen, regardless of peripheral velocity of the lower specimen. In particular, within 10 km of running distance, the roughness of the upper specimen became five times that of pearlite type of D type curve. The roughness shown in Fig. 2(a) was measured by the transverse magnification (×1000) and longitudinal magnification (×100). But with the increase of running distance, the roughness of F-7 of the specimen decreased gradually, as shown in Fig. 2(b). Among F–6～8 of the specimens, it was difficult to recognize the influence caused by the difference of graphite shape. The roughness of the lower specimen, in comparison with the upper specimen, had the changes of ups and downs in narrow ranges. A–7 and 8 of specimens were D type curve and A–6 of specimen was B type curve, as shown in Fig. 1.

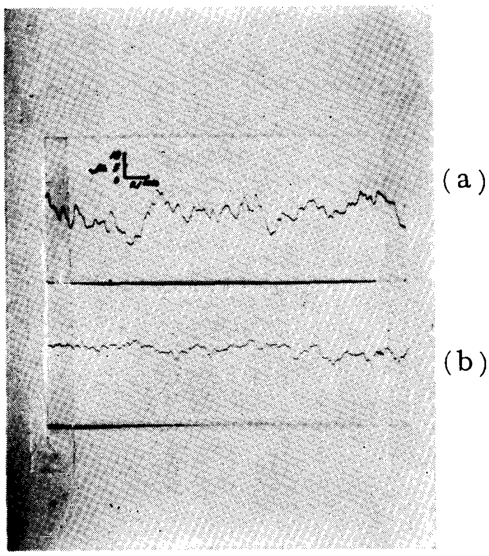


Fig. 2. Ferrite type curve of surface roughness.

The contacting surface of these specimens consists of lustrous area and is extremely rough. Wearing chips show metallic lustre.

On the wearing surface, the roughness differs with the combination of the matrices(4). The upper specimen of ferrite matrix is severely roughened by the lower specimen of pearlite matrix. The matrix has larger influence on the surface roughness than the graphite shape. On the other hand, when the upper and the

(4) A. Selwood, Wear, **5** (1962), 148: N. Meyers, Wear, **5** (1962), 182.

lower specimen are both pearlite matrix, the difference with the shape, size, amount and distribution state of graphite decides surface roughness. When the running distance increases, the roughness of the upper specimen having the large size of graphite shape maintains the state of the early period of running distance. This seemed to be caused by the lubricating acting of graphite.

2. The hardness of wearing surface

The hardness before wear tests was such as shown in Fig. 3.

From P-1 to P-5 of the upper specimen, the hardness of pearlite matrix could be regarded to be the same, although it was pretty scattered. On the other hand, the hardness of ferrite matrix showed gradually higher values from F-6 to F-8, because of their silico-ferrite matrices.

The surface hardness after wear tests was such as shown in Fig. 4.

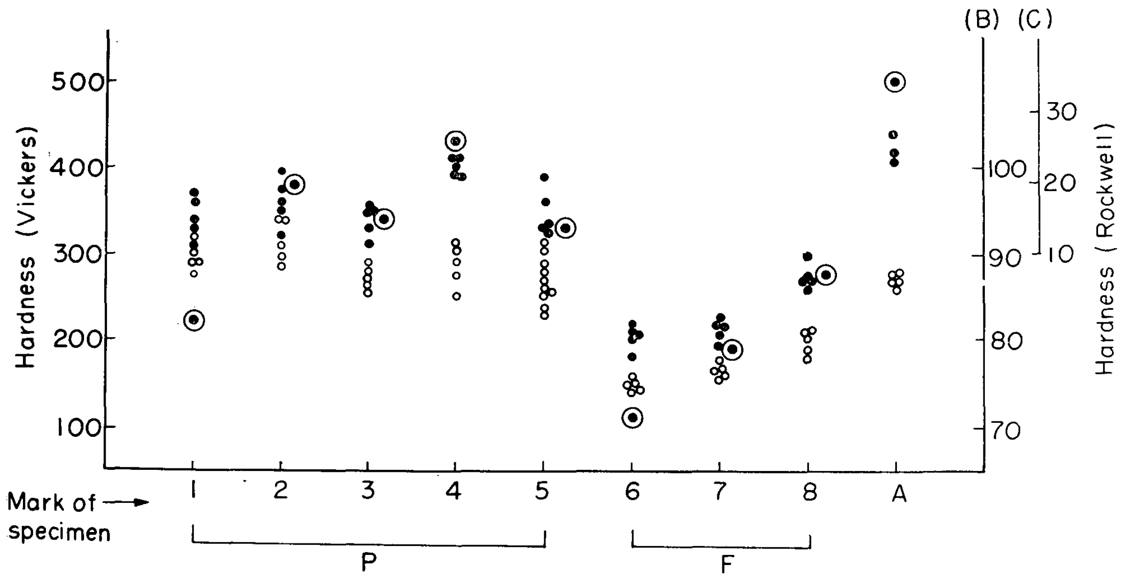
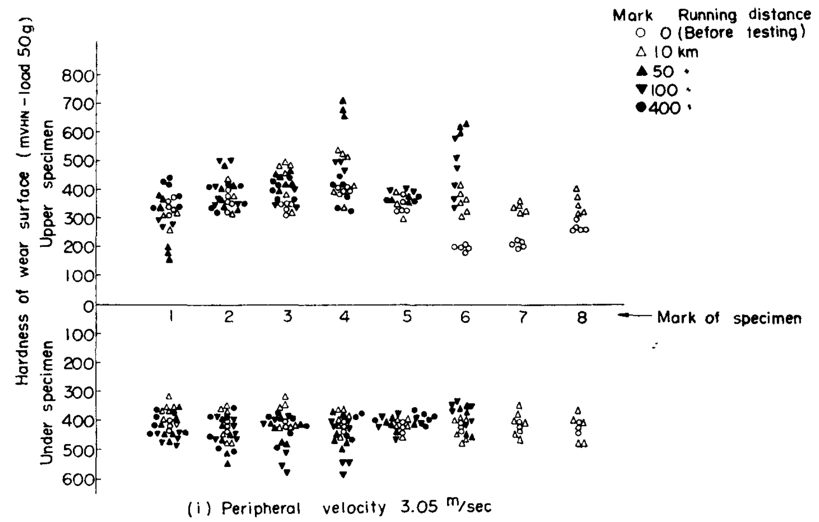


Fig. 3. Hardness of specimens before testing.
⊙ Rockwell hardness
∘ Vickers hardness (load 500 g) (Hardness of matrix)
• Vickers hardness (load 50 g) (Hardness of matrix)

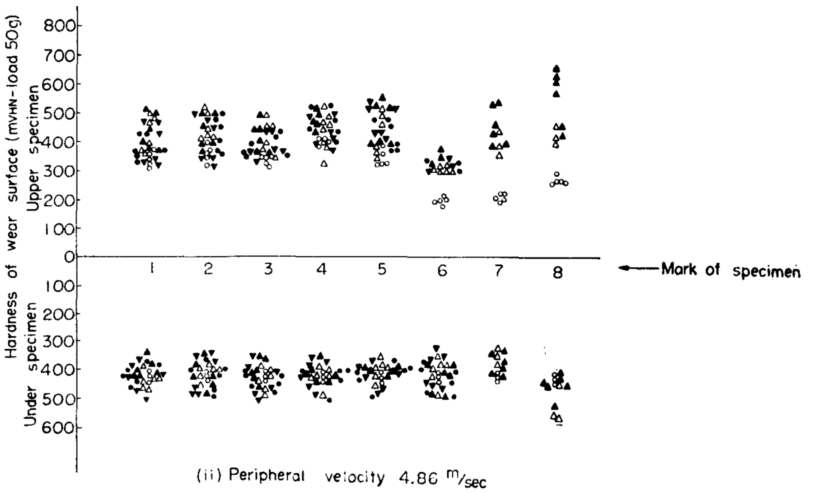
On the pearlite matrix of the upper specimen from P-1 to P-5, the surface hardness showed a constant value regardless of running distance; it was difficult to observe the influence caused by the difference in graphite shapes.

The surface hardness of the upper specimen was affected by the peripheral velocity of the lower specimen. A comparison between 4.86 and 3.05 m/s of the peripheral velocity of the lower specimen showed that the former had higher hardness than the latter. The surface hardness of the lower specimen showed a reverse tendency.

Within 10 km of running distance, the surface hardnesses of F–6∼8 of the upper specimen consisting of ferrite matrices were similar to those of pearlite matrices and it was difficult to observe the influence caused by the difference of



(i) Peripheral velocity 3.05 m/sec.



(ii) Peripheral velocity 4.86m/sec.

Fig. 4. Relation between running distance and hardness of wear surface of specimens.

graphite shapes. The surface hardnesses of the lower specimen didn't show any variation similar to the case of pearlite matrix.

3. The amount of wearing loss

The total sum of wearing amounts on the running distance up to 70 km is shown in Fig. 5. And the wearing amount per 50 km of running distance on the total sum of running distance up to 400 km is shown in Fig. 6. Before the upper specimens consisting of ferrite matrices reached 400 km of running distance, it was difficult to carry out wear tests, because of large amounts of wearing loss. Among the upper specimen of F–6∼8 consisting of ferrite matrices wearing amounts were clearly different, of which F–8 of the specimen was the worst. F–8 and F–7 of the upper specimen showed over 1g of wearing loss at 1958m and 5500m at the peripheral velocity 3.05 m/s and at 25000m and 35000m at the peripheral velocity

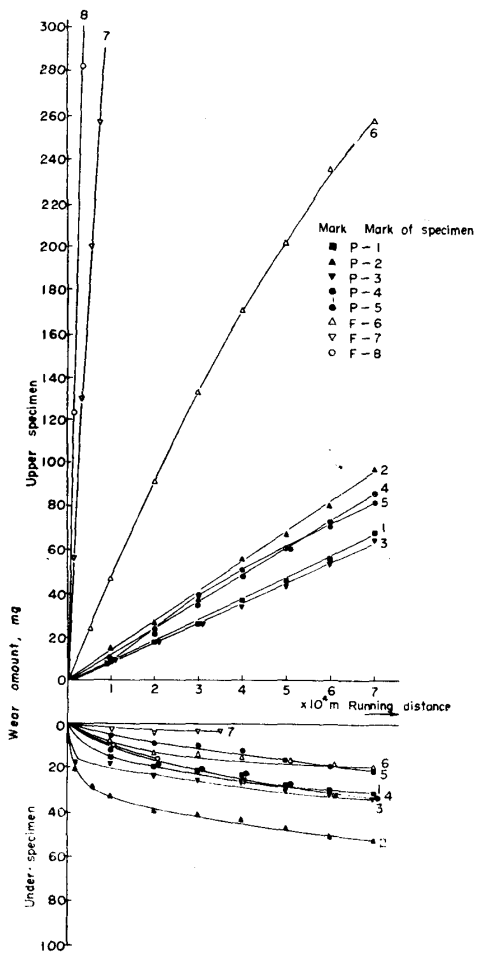


Fig. 5. Cumulative wear amounts at the peripheral velocity 4.86m/s.

4.86 m/s respectively. F-6 of the upper specimen showed over 1 g of wearing loss at 9000m at the peripheral velocity 3.05 m/s and under 1 g at 400 km at the peripheral velocity 4.86 m/s. In other words, on these specimens graphite shapes and silico-ferrite had an important effect on wearing loss, and F-8 of the upper specimen consisting of silico-ferrite containing small graphite nodule showed large wearing amounts.

Among the upper specimen of P-1∼5 consisting of pearlite matrices wearing amounts didn't show any clear difference, contrary to the ferrite matrices mentioned above. However, on the nodular graphite cast iron consisting of pearlite matrices, it was already reported that the specimen containing a large graphite nodule showed better wear resisting properties than those containing a small graphite nodule(5). The amount of wearing loss of both upper and lower specimens showed gradual increase with the variation in graphite shapes of the upper specimen from large to small, i.e., flaky (P-1, 3)—small nodule (P-4)—eutectic (P-5).

4. Micro-structure of the section adjacent to the wearing surface

After wear tests of the running distance up to 400 km, the microstructure of the section adjacent to the wearing surface was inspected.

Regardless of the peripheral velocity of the lower specimen, It could not be observed the occurrence of the degenerative and transition layer on the section adjacent to the contacting surface of ferrite and pearlite matrices. But the deformation was noticed on the contacting surface, similar to that of the previously reported pearlite type (L-1) specimen(1) of nodular graphite cast steel.

The deformation of the contacting surface on ferrite matrix, in comparison with pearlite matrix was large regardless of graphite shape. On the specimen of small graphite shape, the effect of graphite as a lubricant agent disappeared because it was filled with the deformed matrices, and consequently, the wearing amounts increased. On the other hand, the deformation of the contacting surface on pearlite

(5) T. Takase, J. Japan Foundrymen's Soc., **27** (1955), 628.

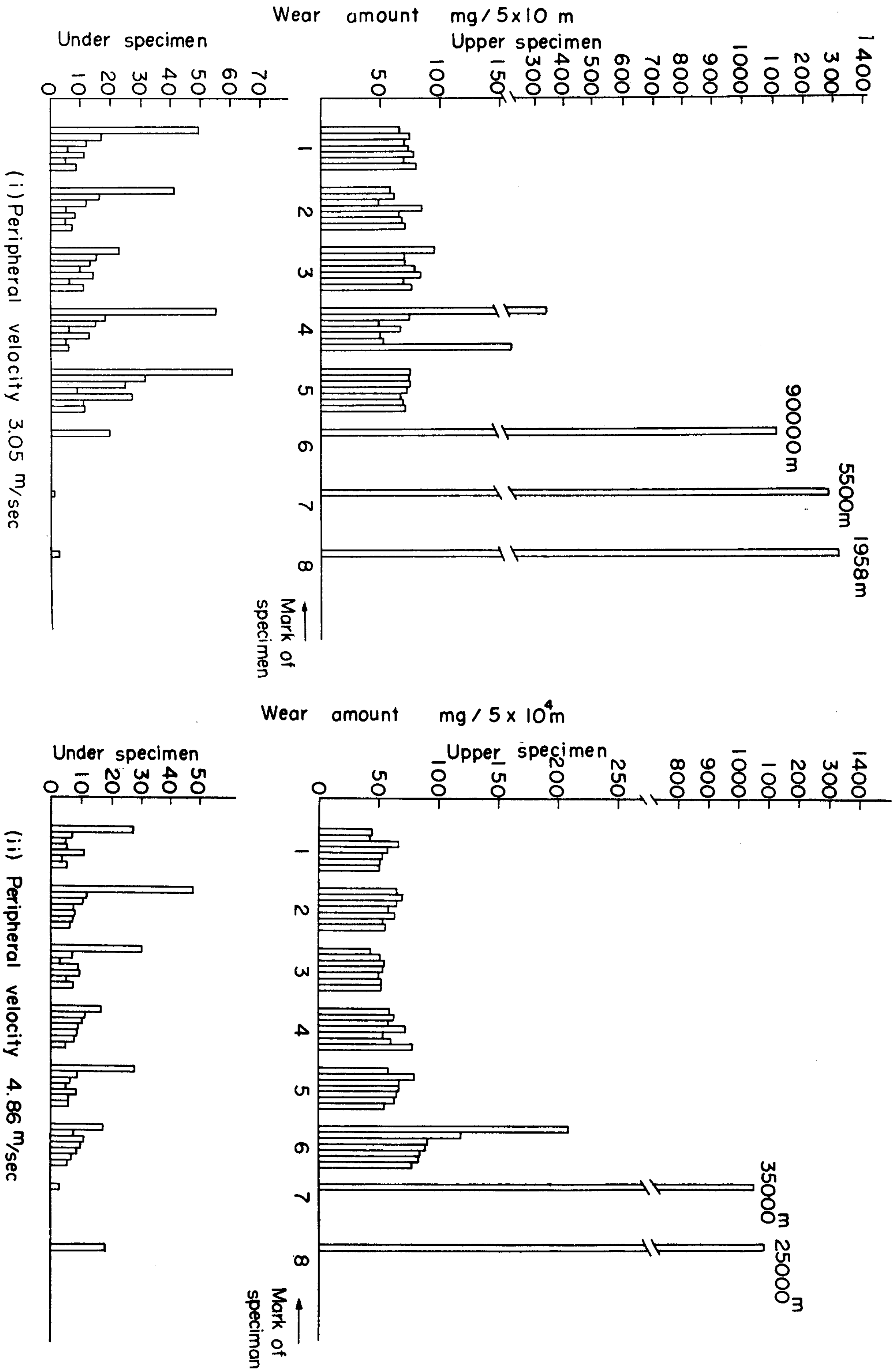


Fig. 6. Wear amounts per 50 km of running distance.

matrix was more difficult of occurrence than that of ferrite matrix, and the wearing amount was less. On the contacting surface of pearlite matrix containing small size of graphite shape, both the tensile strength and the resistance for the deformation were large, but the effect as a lubricant agent of graphite was small. On the contrary, when graphite shape was large, the effect as a lubricant agent of graphite was large, but the tensile strength and the resistance for the deformation were small[6].

In consequence, it seems that the shape, size, amount and distribution state of graphite are necessary in order to operate as a lubricant agent within the limits of maintaining sufficient tensile strength of materials to prevent the deformation.

Summary

The upper specimens are cast irons of different graphite shapes and matrices, and the lower specimen are the nodular graphite cast steel obtained by normalizing treatment. The wear resisting properties of these various cast irons have been studied. On the running distance up to 400 km the results obtained are as follow:

(1) The surface roughness is influenced by the combinations of the matrices between the upper and lower specimen. In particular, when the matrix of the upper and lower specimen is the same, the surface roughness is influenced by the shape, size, amount and distribution state of graphite.

(2) The surface hardness differs with the matrices, but it shows the constant values determined by the peripheral velocity of lower specimen, regardless of the shape, size, amount and distribution state of graphite and the increase of running distance of upper specimen.

(3) The wearing amounts of the upper and lower specimen differ with combinations of matrices, i.e., the upper specimen of ferrite matrix combined with the lower specimen of pearlite matrix is less wear resisting, and among the upper specimens consisting of ferrite matrices, it has a tendency to show less wear resistivity from large to small nodule of tempered graphite shape. And among pearlite matrices the wearing amount shows gradual increase with the variation in graphite shapes from flake to eutectic.

In conclusion, the author would like to express his thanks to Professor M. Homma for his encouragement throughout the work.

(6) M. Nakai, S. Saito and K. Okamoto, J. Japan Foundrymen's Soc., **33** (1961), 114.