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INVESTIGATION OF ANTIFRICTION PROPERTIES OF COPPER ALLOYED MAGNESIUM CAST IRONS

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25 August 1972

AD750519

FTD-HC-23-1017-72

FOREIGN TECHNOLOGY DIVISION

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14

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Foreign Technology Division Air Force Systems Command U. S. Air Force	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

INVESTIGATION OF ANTIFRICTION PROPERTIES OF COPPER ALLOYED MAGNESIUM CAST IRONS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Translation

5. AUTHOR(S) (First name, middle initial, last name)

Yu. Lerner, A. Get'man

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
1969	10	6

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 7343 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) FTD-HC-23-1017-72 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Foreign Technology Division Wright-Patterson AFB, Ohio

13. ABSTRACT

The wear resistance of copper alloyed (0.54-1.45%) magnesium cast iron is investigated. The comparative data on wear resistance during the reciprocating motion of different friction pairs show the advantages of magnesium cast iron alloyed with 1.15% copper (wear coefficient K equals 0.35), over bronze OTsS 5-5-5 (K equals 1.57) and magnesium cast iron alloyed with 0.5% P (K equals 0.93). Wear resistance testing with hardened rollers of magnesium cast iron specimens, alloyed with 1.15% Cu (K equals 0.37), produced results which were twice higher than those of bronze specimens AKh 9-4 (K equals 0.74). It is recommended to use 1-1.2% Cu alloyed magnesium cast iron as an antifriction material for manufacturing parts working in loaded friction assemblies. [AR1016058]

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Nodular Iron						
Cast Iron						
Magnesium Containing Alloy						
Copper Containing Alloy						
Bibliography						
Friction						
Bronze						
Alloy Designation						
Antifriction Material						
Component Life Expectancy						
Wear Resistance/(U)AKh 9-4 Bronze						
(U)OTsS 5-5-5 Bronze						

FTD-HC-23-1017-72

UNEDITED ROUGH DRAFT TRANSLATION

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English pages: 10

Source: Povysheniye Dolgovechnosti Litykh Materialov, (Increasing the Life Expectancy of Cost Materials), 1969, pp. 59-72.

Requester: ASD/AFML

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INVESTIGATION OF ANTIFRICTION PROPERTIES OF COPPER ALLOYED MAGNESIUM CAST IRONS

[Article by Yu. S. Lerner, A. A. Get'man; Kiev, Povysheniye Dolgovechnosti Litykh Materialov, Russian, 1969, pp 59-72]

Research aimed at determining wear resistance of magnesium cast iron alloyed with copper under various friction conditions are reviewed. Antifriction properties were investigated for the purpose of choosing the optimal cast iron compositions.

Magnesium irons alloyed with copper are promising materials for parts operating under conditions of wear. However they are not yet used sufficiently in industry due to the lack of or contradictory nature of data on their properties.

The differences in the results of investigations [1-3] do not permit definitive characterization of the effect of copper on the antifriction properties of magnesium cast iron.

Experimental research works aimed at determination of the wear resistance of magnesium cast irons alloyed with copper under various friction conditions are presented in this article. The investigations of the antifriction properties were done for the purpose of selecting the optimum compositions of cast iron. All studies are divided into two consecutive stages -- laboratory and operational tests under operational conditions in accordance with standard procedures [4-6].

The laboratory tests were conducted in comparison with magnesium cast irons of various structure and bronzes during reciprocating motion on a special test stand and during rotary motion on an MI-1 friction machine. The basic data on the chemical composition, hardness and microstructure of friction pairs tested for wear are presented in Table 1.

Table 1. Basic Data on Chemical Composition, Hardness and Microstructure of Friction Pairs Investigated for Wear

Material	Chemical composition, %							Average Brinell hardness	Microstructure
	C	Si	Mn	S	P	Mg	Cu		
1	2	3	4	5	6	7	8	9	10
Initial magnesium cast iron	3.34	2.49	0.65	0.008	0.086	0.046	--	255	Graphite spherical, metallic base perlitic
Magnesium cast iron alloyed with 0.54% Cu	3.20	2.6	0.58	0.005	0.06	0.066	0.54	273	Same
Magnesium cast iron alloyed with 0.82% Cu	3.38	2.7	0.72	0.004	0.07	0.045	0.82	285	"
Magnesium cast iron alloyed with 0.15% Cu	3.25	2.76	0.7	0.004	0.08	0.005	1.15	298	"
Magnesium cast iron alloyed with 1.45% Cu	3.30	2.55	0.63	0.008	0.085	0.074	1.45	302	"
Isothermically hardened magnesium cast iron	3.20	3.0	0.7	0.02	0.07	0.045	--	225	Graphite spherical, metallic base sorbite-ferrite
Magnesium cast iron alloyed with 0.5% P	3.25	2.34	0.75	0.005	0.052	0.072	--	269	Graphite spherical, metallic base perlitic, inclusions of binary phosphide eutectic in form of broken lattice
Bronze OTsS-5-5-5	Tin 4.5	Zinc 4.8	Lead 5.4	--	--	--	85.2	78	Metallic base α-solid solution, through cross section uniformly distributed inclusions of lead, round and oblong in shape

(Continued)

Table 1. (Continued)

1	2	3	4	5	6	7	8	9	10
Bronze AKh 9-4	Aluminum 8.5	Iron 3.0	--	--	--	--	88.5	114	Metallic base α-solid solution and eutectoid, through cross section uniformly distributed Al_3Fe_2 inclusions of round and angular shape

The tests on the reciprocating machine were conducted under conditions of friction with lubricant. We used for the tests cylindrical specimens 10 mm in diameter and 18 mm high. They were installed and fixed in a head consisting of two attached discs with three holes for the specimens. We used plates made of normalized steel 45 as the mated pair. On each plate were three slide grooves; the total area of the working surface of the three simultaneously tested specimens was 2.41 cm^2. The sliding surfaces of the specimen and the plate were rubbed on a cast iron rubbing plate with the aid of abrasive powder. The specimens and the plate were carefully washed with benzene before and after the tests and weighed after drying in an air oven at a temperature of 80-100°C. The wear of the tested specimens and of the plates was determined according to the weight difference before and after the tests.

The tests with reciprocating motion were done under the following conditions: wear-in of the specimens was done at a specific pressure of 60 kg/cm^2 at an average slide rate of 0.45 m/sec for 60 minutes, which corresponds to a path of friction of 1,600 m; wear of the specimens was determined for specific pressures of 60 kg/cm^2 and average sliding rate of 0.45 m/sec; the time of one experiment was 8 hours, which corresponds to a path of friction of 12,800 m. The friction grooves were oiled through the three holes from the inside of the head. During the tests the oil was used at a rate of one drop per minute. The temperature of the oil in the reservoir was maintained within 18-20°C. To ensure constant temperature of the sliding surfaces the removable head was cooled with water. This made it possible to maintain the temperature of the sliding surfaces constant within 60-70°C, which excluded the effect of the viscosity of the oil on the test results.

The data of the comparative wear tests of the investigated materials in reciprocal motion are presented in Table 2.

Comparison of the wear of the tested friction pairs was done on the basis of wear coefficient K_u, which was determined for the specimens and mated pair with the formula:

$$K_u = \frac{\Delta P_n}{\Delta P_0},$$

where ΔP_n is the weight loss of the tested specimen or plate mated to it, in mg;

ΔP_0 is the weight loss of the specimen of initial magnesium cast iron or plate mated to it, in mg.

The curves of wear of specimens of copper-alloyed magnesium cast iron and of steel plates working in pair with them are shown in Figure 1 as a function of the copper concentration. As seen by analyzing the test results, when the copper concentration in the magnesium cast iron is decreased to 1.45% the wear of the cast iron specimens decreases more than three-fold. Reduction of the wear of specimens with a copper concentration of 0.82-1.15% is most effective; a further increase in copper concentration from 1.15 to 1.4% decreases wear only slightly: the wear coefficient decreases from 0.35 to 0.3.

Table 2. Results of Comparative Tests of Investigated Materials under Conditions of Friction with Lubrication during Reciprocating Motion

Material	Average wear, mg		Wear coefficient	
	specimen	plate	specimen	plate
Initial magnesium cast iron	16.4	19.6	1.0	1.0
Magnesium cast iron alloyed with 0.54% Cu	13.1	20.8	0.8	1.06
Magnesium cast iron alloyed with 0.82% Cu	10.5	21.0	0.64	1.07
Magnesium cast iron alloyed with 1.15% Cu	5.8	22.8	0.35	1.16
Magnesium cast iron alloyed with 1.45% Cu	5.0	23.5	0.3	1.2
Magnesium cast iron alloyed with 0.5% P	15.3	22.7	0.93	1.16
Bronze OTsS 5-5-5	25.7	20.3	1.57	1.02

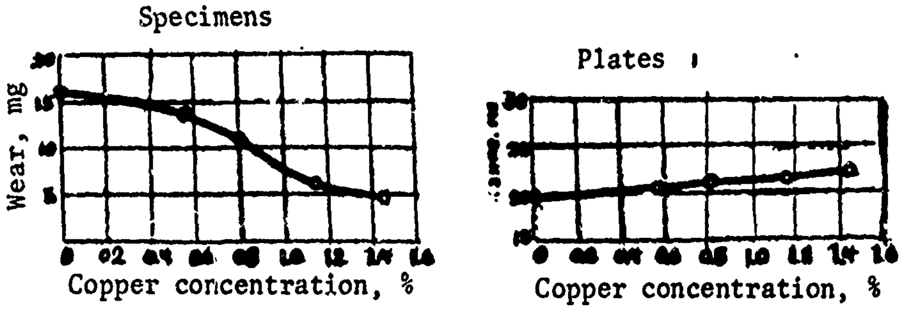

Figure 1. Wear resistance of magnesium cast iron alloyed with copper under conditions of friction with lubrication during reciprocating motion.

An increase in the copper concentration of magnesium cast iron increases somewhat the wear of the mated pair: the wear coefficient increases to 1.2.

The comparative data of wear resistance in the case of reciprocating motion of various friction pairs (Figure 2) showed the advantage of magnesium cast iron alloyed with 1.15% Cu (K_u = 0.35), over bronze OTsS 5-5-5 (K_u = 1.57) and magnesium cast iron alloyed with 0.5% P (K_u = = 0.93).

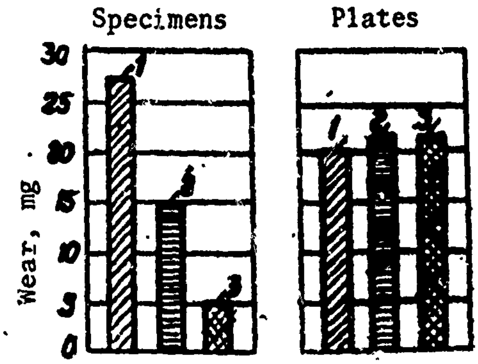

Figure 2. Comparative wear resistance of various friction pairs during tests with lubrication on rotary-reciprocating motion machine: 1 -- bronze OTsS 5-5-5; 2 -- magnesium cast iron alloyed with 0.5% P; 3 -- magnesium cast iron alloyed with 1.15% Cu.

The wear of the plates operating in pair with the magnesium cast iron alloyed with 1.15% Cu (K_u = 1.16) differed very little from that of plates operating with bronze OTsS 5-5-5 (K_u = 1.02) and magnesium cast iron alloyed with phosphorus (K_u = 1.16).

During tests on the MI-1 friction machine the sliding pair consisted of a specimen made of the tested material and a steel roller. Steel rollers, 30 mm in diameter and 11 mm wide, depending on the test conditions, were used in the normalized state or after hardening to 48-52% RC units. The amount of wear was determined on the basis of the weight difference of the specimens before and after the tests. Before weighing the specimens were washed with benzene and dried in an air oven. The tests were conducted with lubrication at a specific pressure of 75 kg/cm^2 at a roller rotation rate of 0.31 m/sec. The oil was supplied to the sliding pair at a rate of 6-8 drops per minute. Before the test all specimens were prerubbed against the steel rollers at a specific pressure of 75 kg/cm^2. The criteria of rubbing were complete breaking in of the mated friction surfaces and steady-state moment of friction. The test time for rubbing with lubrication was 20 hours.

To determine the friction coefficient during the tests the friction moment was recorded with a special instrument.

During the investigations each test was repeated three times.

Results of comparative wear tests of various friction pairs are presented in Table 3 and shown graphically in Figures 3 and 4. As seen, the tests using an unhardened roller showed higher wear of the specimens and rollers mated with them in all investigated versions, compared with the test specimens mated with a hardened roller. In the test with an unhardened roller (Figure 3) the wear resistance of the magnesium cast iron alloyed with copper is 1.5 times greater; the wear of the mated pair increases somewhat (K_u = 1.17).

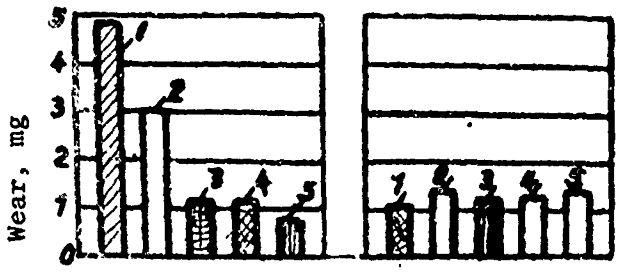

Figure 3. Comparative wear resistance of various friction pairs tested with lubrication on the MI-1 machine with unhardened roller: 1 -- bronze OTsS 5-5-5; 2 -- bronze AKh 9-4; 3 -- initial magnesium cast iron; 4 -- isothermically hardened magnesium cast iron; 5 -- magnesium cast iron alloyed with 1.15% Cu.

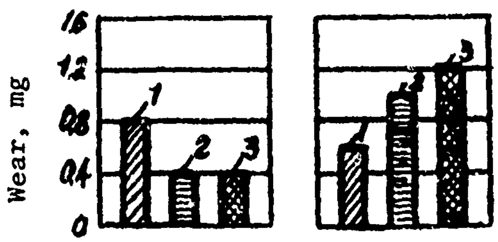

Figure 4. Comparative wear resistance of various friction pairs tested with lubrication on MI-1 friction machine with hardened roller: 1 -- bronze AKh 9-4; 2 - magnesium cast iron alloyed with 1.15% Cu; 3 -- magnesium cast iron alloyed with 1.45% Cu.

The increase in the wear resistance of the specimens is small in the range of Cu concentrations of 1.15-1.45%: the wear coefficient decreases from 0.66 to 0.58. Here the roller wear increases slightly: the wear coefficient increases from 1.08 to 1.17.

Comparison of results of the tests of various friction couples with an unhardened roller reveals that magnesium cast iron alloyed with 1.15% Cu (K_u = 0.66) is superior in terms of wear resistance to isothermically hardened magnesium cast iron (K_u = 0.92) and bronzes OTsS 5-5-5

(K_u = 4.0) and AKh 9-4 (K_u = 2.6). The wear of the mated rollers of the compared cast irons and bronze AKh 9-4 is identical (K_u = 1.08); the roller working in pair with bronze OTsS 5-5-5 wore somewhat less (K_u = 0.92).

Table 3. Results of Comparative Tests on MI-1 Machine under Conditions of Friction with Lubrication with Hardened and Unhardened Rollers

Material	Average wear, mg		Average friction coefficient	Wear coefficient	
	specimen	roller		specimen	roller
With unhardened roller					
Initial magnesium cast iron	1.2	1.2	0.042	1.0	1.0
Magnesium cast iron alloyed with 1.15% Cu	0.8	1.9	0.086	0.66	1.08
Magnesium cast iron alloyed with 1.45% Cu	0.7	1.4	0.086	0.58	1.17
Isothermically hardened magnesium cast iron	1.1	1.8	0.058	0.92	1.08
Bronze OtS 5-5-5	4.8	1.1	0.010	4.0	0.92
Bronze AKh 9-4	3.0	1.3	0.012	2.5	1.08
With hardened roller					
Magnesium cast iron alloyed with 1.5% Cu	0.4	1.0	0.030	0.37	0.88
Magnesium cast iron alloyed with 1.45% Cu	0.4	1.2	0.30	0.37	1.0
Bronze AKh 9-4	0.8	0.6	0.10	0.74	0.5

During tests with a hardened roller (see Figure 4) the wear resistance of specimens of magnesium cast iron alloyed with 1.15% Cu (K_u = 0.37) was twice that of specimens of bronze AKh 9-4 (K_u = 0.74). The wear coefficient of the roller in this case increases from 0.5 to 0.88. Alloying of magnesium cast iron with copper from 1.15 to 1.45% is also ineffective in this case.

The wear coefficients for alloying of magnesium cast iron with copper decreases from 0.042 to 0.036 in tests with the unhardened roller. There is also a reduction of the friction coefficient to 0.030 during tests with a hardened roller.

As shown by the results of laboratory tests, an effective increase in the antifriction properties of magnesium cast iron occurs at a copper concentration of 1.15%, when about half of it is in the free state as finely dispersed inclusions of excess phase.

The comparative data of the wear resistance of various friction pairs revealed that in terms of antifriction properties magnesium cast iron alloyed with 1.15% copper is superior to ordinary nonalloyed and phosphorus-alloyed magnesium cast iron and is not inferior to bronzes.

This position is confirmed by industrial tests under operating conditions in various operating modes of several parts of forge-pressing machines.

The blanks of the parts were cast into dummies 100 mm in diameter and 250 mm long and bushings with an outside diameter of 160 mm, inside diameter of 100 mm and length of 200 mm. The cupola-melted cast iron was treated with magnesium in a hermetically sealed autoclave chamber and alloyed with copper. The blanks were cast from cast iron of the following chemical composition: 3.2-3.4% C, 2.5-2.7% Si, 0.6-0.8% manganese, up to 0.12% P, up to 0.03% S, 1.0-1.2% Cu, 0.046-0.067% Mg.

The friction bearings made from these blanks were installed on bend rollers (spindle inserts), forge hammers (piston ring inserts) and sheet metal shears (shaft bushings) for the operational tests. Bronze bushings were formerly used in these journals. The operating conditions of the parts in the journals are characterized by the following parameters:

Bend rollers -- specific pressure 180 kg/cm^2; peripheral velocity 0.78 m/sec; shaft -- steel 45, normalized; lubrication -- periodic with grease.

Forge hammers -- specific pressure 46.7 kg/cm^2; circumferential velocity 0.4 m/sec; shaft -- steel 20, carborized; lubrication -- periodic with grease.

Sheet metal shears -- specific pressure 162 kg/cm^2, circumferential velocity 0.75 m/sec; shaft -- steel 45, hardened; lubrication -- centralized with grease.

The comparative operational tests of bushings of bend shafts made of magnesium cast iron alloyed with copper, and of bronze OTsS 5-5-5, conducted in the forge-press shop of the October Revolution factory showed that the service life of cast iron bushings is twice that of bronze bushings. The results of operation of experimental friction journals of other machines showed slight wear and high longevity of bushings made of cast iron alloyed with copper, and the possibility of replacing expensive bronze.

On the basis of laboratory studies and operational tests magnesium cast iron alloyed with 1-1.2% Cu can be recommended as an antifriction material for the manufacture of parts operating in stressed friction journals.

The antifriction properties of magnesium cast iron are improved by alloying with copper as a result of the action of the copper on the nature of the metallic base. The finely dispersed inclusions of excess copper, separating in excess of the limiting solubility, act as extra lubrication in the friction process.

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