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TESTING OF POTENTIAL BEARING MATERIALS IN AN
ARGON ATMOSPHERE OF LOW HUMIDITY

by

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ABSTRACT

Bearing materials for use in the Metallurgy Division Sector of the EBR-II Fuel Cycle Plant must operate without lubrication in an argon atmosphere of low humidity (dew-point of -50°C or less) and high gamma activity. To select suitable materials, a test program, in which samples of materials known to be radiation resistant were tested for wear resistance in an argon atmosphere containing less than 30 ppm water by volume, was initiated. The criterion by which wear resistance was judged is loss in sample weight over a 24-hour abrasion period during which the samples rub along the periphery of a $2\frac{1}{2}$ -in. OD wear ring made of SAE 1045 steel. The majority of the samples were tested using a load of 2755 gm and a rubbing velocity of 109 ft per sec. Contact between the rectangular samples and the wear ring was initially linear.

Of the materials tested, Reactor Grade Graphite and some graphite derivatives showed the best bearing qualities. A group of steel samples coated with impregnated plastic also showed desirable properties. While they are not as wear resistant as the best graphitic samples, their superior physical properties give them a wider range of application.

INTRODUCTION

The operating components for the Metallurgy Division Sector of the EBR-II Fuel Cycle Plant are expected to function efficiently in a predominantly argon atmosphere of low humidity. In addition, a high level of alpha and gamma activity is expected, since at least one 10-kg batch of irradiated fuel alloy will be present in the cell much of the time. It is paramount that all operating components be constructed of materials not appreciably affected by the irradiation to which they are subjected. Since the degree of irradiation is a function of the size and proximity of the source, it is not assumed that all components will be subjected to the same degree of irradiation; however, pending additional information, a design practice of avoiding the use of organic materials was initiated.

The limitations imposed by this practice on the selection of component actuating mechanisms is obvious. Those requiring lubricants, organic fluids, or electrical insulation are immediately excluded. Gas-powered mechanisms are suitable. On the basis of low gas consumption, ready adaptability to the motions required, and simple rugged metallic construction, gas-operated pistons were selected. Only their piston rings seals are organic. Replacing the organic seals with inorganic seals produces an actuating mechanism unaffected by irradiation.

The purpose of this experiment was to select one material from a group known to be radiation resistant to serve as a seal. Because the seals rub against the cylinder walls while the piston is in operation, the criterion of acceptance is wear resistance when acting as a member of a wear couple with steel. Little is known concerning the wearability of unlubricated materials in dry inert atmospheres, so a testing program was necessary to make an intelligent selection.

The program was divided into two primary phases: (1) the establishment and maintenance of the desired atmosphere and (2) the preparation and testing of samples furnished by commercial suppliers. Most of the samples are graphite derivatives; however, some metals and metal coatings were also tested. The criterion by which wear resistance is judged is sample weight lost during a 24-hour abrasion period.

WEAR-TESTING EQUIPMENT

The wear-testing machine selected for this project will operate in a glovebox; thus, simplicity is the primary criterion of selection. Simplicity of operation is important as well as ease of maintenance, which includes resurfacing of the wear rings. Because of the many samples to be tested, it is advantageous for the testing machine to have several wearing surfaces so that several samples can be tested simultaneously. It is necessary to have large variations of testing loads and speeds available. The immediate problem is the selection of a suitable material to act as piston ring type seals for gas-operated pistons. The conditions under which these seals operate are essentially low load and low speed; however, it was hoped that some information concerning the suitability of materials for journal bearings could also be acquired. For journal applications, it is necessary to use higher testing loads and speeds.

Another concern in the selection of a testing machine is whether or not to use a machine capable of unidirectional motion only. It is known that graphite, whose derivatives constituted the bulk of the samples, has directional properties. Initially the wear rate of a graphite sample is relatively high; however, the wear rate usually decreases after a small run-in period. If the direction of rubbing is reversed, as it is in piston applications, the wear rate increases for another run-in period. Thus it is not to be expected that unidirectional rubbing will produce the same wear rate as reciprocating rubbing.

In spite of the directionality problem it was decided to use a testing machine having unidirectional rubbing for the following reasons: (1) the construction and resurfacing of the machine, which must be done in the glovebox, is appreciably simplified; and (2) some information as to the effect of changes in rubbing direction can be acquired by observing the rate of wear during different portions of the test. Materials having relatively large wear during the run-in period should show a proportionately higher wear rate early in the test.

A picture of the wear-testing machine designed for this project is shown in Figure 1. It consists primarily of a series of eight $2\frac{1}{2}$ -in. OD wear rings of SAE 1045 steel and seven fluted copper spacers mounted on a spindle. Each end of the spindle is supported by a pillow block. One end is connected by a Boston Gear coupling to a $3/4$ -hp variable-speed DC motor. For rigidity the machine was mounted on a steel base. The over-all dimensions of the test machine are approximately 12 x 14 x 40 in.

Figure 1 View of Testing Machine

An aluminum lever arm containing a specimen clamp is located over each wear ring (see Figure 2). The arms are $6\frac{7}{8}$ -in. long, $1\frac{1}{4}$ -in. wide, and $3/8$ -in. thick. The critical dimensions used in calculating the load on the specimens are as follows: the distance from the center of the pivot to the center of the wear specimen holder is 3.00 in.; the distance from the center of the pivot to the center of mass of the lever arm is 3.53 in.; and

the distance from the center of the pivot to the center of the weight hanger is 6.00 in. The lever arms weigh 161 gm each and the weight hangers, which attach the weights to the lever arms, weigh 102 gm each. Each lead weight weighs 236 gm. The weight difference between lever arms, weight hangers, and weights for the various stations is less than one per cent of the weight given. All samples weighed between 1 and 3 gm. Since all other weights are to the nearest gram, an average figure of 2 gm can be used for all samples without introducing any inaccuracy into the load calculations. The test loads possible with this machine are 395, 867, 1339, 1811, 2283, and 2755 gm with 0, 1, 2, 3, 4, and 5 weights respectively.

Figure 2 View of Testing Machine Showing Lever Arms and Weights

The range of ring speeds possible is 400 to 1500 rpm. Speed is controlled by a Variac and measured by a generator tachometer. The speed is recorded on an Esterline-Angus recording rpm meter outside the glovebox. The current input to the test machine is also recorded on a General Electric recording ammeter outside the box (see Figure 3).

Figure 3 Testing Machine Control Panel

Before the test machine was sealed in the glovebox, it was tested for vibration and as much dampened as possible. The test machine, with enough tools to operate and repair it, were then put inside the glovebox.

Since the criterion chosen to indicate wear is sample weight change, a balance is also needed in the glovebox. A Mettler Gram-Matic balance, capable of measuring to 0.1 mg, was used. This is a gas-dampened balance and can therefore be affected by pressure changes; however, when reasonable care is exerted no change in accuracy is detectable. Weights taken while gas is flowing into the glovebox or while the temperature of the hood atmosphere is changing are not reproducible. Weights taken under quasi-static conditions are reproducible to the limit of measurement of the balance.

TESTING ATMOSPHERE

A. Glovebox Modifications

The atmosphere desired for the wear tests is predominantly one of argon gas of low humidity (dewpoint of -50°C or less) and low activity of contaminants. No specifications are put on contaminants other than moisture.

It was deemed necessary to have a comparatively leaktight glovebox connected to a source of argon gas through a drying train. The gas can be used to replace that leaking from the glovebox and maintain the pressure inside higher than atmospheric to insure that all leakage is outward. Because of moisture adsorbed on the walls and equipment in the box at sealing, it is necessary to have a gas purification system capable of removing moisture from the box. It can utilize the same drying train as the tank gas or can be a separate system. An oxygen-removing device should be included in the drying train and consist of a steel U-tube filled with copper wool and maintained above 500°C .

The glovebox selected was a Plutonium Fabrication Facility prototype glovebox of the type shown in Figure 4. It consists of an aluminum alloy structure supporting windows of allyl diglycol carbonate plastic manufactured by the Cast Optics Corporation of Riverside, Connecticut. The box is divided into two connected compartments, one having a 144-cu ft capacity and the other a 96-cu ft capacity, by means of an aluminum alloy plate fitted with a door. Each compartment is fitted with gloveports so arranged as to make every portion of the glovebox interior accessible through neoprene gloves. This box was selected because of its availability and low rate of leakage at pressures close to atmospheric (0.02 cu ft per hour per 100-cu ft capacity under pressure differential of 2 in. of water).

Figure 4 Glovebox

To make the box suitable, it was necessary to add the following items:

1. power feed-throughs
2. gas inlets and outlets
3. pressure gauge
4. pressure-sensing device
5. entrance bag

All additions were made by installing the item added in a gloveport cover and installing the cover over one of the upper gloveports

The leads necessary to bring in power to the wear-testing machine and balance and to bring the signal from the tachometer out to the recording rpm meter were supplied by a single, 14-connector Amphenol plug

fitting into a receptacle soldered into a brass gloveport cover. Gas inlets and outlets were also added. One inlet was needed to permit gas from the supply system to enter the hood. An inlet and an outlet were required to connect the gas purifying system to the glovebox. Two inlets were required which connect inside the box to the displacement bags, and two outlets were required for sampling the glovebox atmosphere.

Pressures inside the box are indicated to the operator by a direct reading Magnahelic pressure gauge capable of indicating pressures in the range of 0 to 4 in. of water gauge. Two pressure-sensing switches (Type SB, Model 187 UC manufactured by United Electrical Controls) are also needed. One switch controls a solenoid valve in the gas supply line. When the pressure inside the box drops below 0.3 in. of water (gauge), the valve in the gas supply line is opened and kept open until the pressure reaches 1.0 in. If the pressure reaches 1.5 in. of water (gauge), the second pressure switch actuates a solenoid valve in an outlet line and allows the excess gas to exhaust to the atmosphere. This safety valve is quite important when displacing the gases present in the box at sealing.

One gloveport is fitted with a polyethylene entrance bag to be used in taking test samples in and out of the glovebox without contaminating the testing atmosphere (see Figure 5). The technique used is essentially that

Figure 5 Glove Entrance Bag

described by Kelman, Wilkinson, Shuck, and Goertz.* When the suggested additions are made the glovebox is suitable for use (see Figures 6 and 7).

B. Gas Supply System

The function of the gas supply system is to furnish dry argon gas to compensate for leakage from the glovebox. A bank of five tanks of welding-grade argon is connected to a manifold. To keep the activity of water vapor in the manifold gas low, the total pressure in the manifold is kept above 900 psig. A pressure regulator on the outlet side of the manifold reduces the line pressure to 10 psig and a Rotameter type flowmeter reduces the gas flow through the system to 20 cu ft per hour. From the flowmeter the argon passes through a solenoid valve, activated by a pressure-sensing switch, to the primary drying train and into the glovebox. All auxiliary systems were helium leak-checked before being connected to the glovebox.

The primary drying train consists of three 5-ft-high U-tubes made of 2-in. ID copper tubes. Each U-tube contains 11 lb of Type 4A Molecular Sieves purchased from the Linde Company. By means of valves and bypasses, each U-tube can be isolated and the Molecular Sieves removed for regeneration at 260°C. The long life of the sieve in the primary drying train and the short regeneration cycle makes the method of removing the sieves for regeneration preferable to in-place regeneration. With the atmosphere established and make-up gas only passing through the system, the Molecular Sieves function successfully for two weeks or more before regeneration is necessary.

C. Gas Purification System

This system is designed to remove moisture and oxygen from the glovebox atmosphere. It is necessary because of the moisture in the atmosphere and adsorbed on the walls of the box at sealing and also because of the moisture entering by diffusion through the gloves. To remove this water the gases inside the box must be circulated through an external purification system.

The system consists of a pump, two 5-ft-high U-tubes of 2-in. ID copper tube, and two U-tubes of 2-in. ID pipe. The copper tubes contain 11 lb each of Molecular Sieves and are fitted with nichrome windings and air connections for in-place regeneration. The steel tubes contain approximately 1/2 lb of copper wool each and are also fitted with nichrome windings for operation at 500°C. The ends of the pipes are closed with a conventional pipe plug sealed with Silver Goop, a thread lubricant distributed by the

*L. R. Kelman, W. D. Wilkinson, A. B. Shuck and R. C. Goertz, "The Safe Handling of Radioactive Pyrophoric Materials," ANL-5509 (Dec. 1955).

Figure 6.

Flow of Argon in Glovebox System

Figure 7.

Schematic Glovebox System

Crawford Fitting Company. The hot copper turnings are intended for oxygen removal. The two types of U-tubes are in parallel, allowing one set to be readied while the other is in service. The recirculating pump is made by the Gast Manufacturing Company of Benton Harbor, Michigan. It is a positive displacement-type, graphite-vane pump having a capacity of over 30 cu ft per minute. It was operated in a wet atmosphere (an open room) for 24 hours prior to its introduction into the system. Experience shows that this type of run-in period extends vane life in dry atmospheres appreciably.

Practice consists of pumping gas from the glovebox through a U-tube containing Molecular Sieves to a U-tube containing copper wool at 500°C. It then flows through 3/8-in. OD copper tubing to a flowmeter and back into the glovebox. Valves located between the components allow each one to be isolated and, if necessary, the system as a whole to be isolated from the glovebox. This allows the pumps to be changed without polluting the testing atmosphere. A flow rate of 25 cu ft per hour was maintained by controlling a valve in the pump bypass line. When in operation, the gas purification system ran continuously.

D. Gas Analyzing System

The testing atmosphere was analyzed continuously for moisture, using a Moisture Monitor manufactured by the Consolidated Electrodynamics Corporation of Pasadena, California (see Figure 8). It consists primarily of an electrolytic cell having electrodes coated with phosphorous pentoxide. As gas flows through the cell, water is adsorbed on the electrodes and electrolysed. Readings are obtained from an ammeter calibrated to read in ppm by volume of water when the rate of flow of sample gas through the cell is 100 cu cm per min.

As received, the Moisture Monitor Rotameter is calibrated for dry nitrogen and recalibration for dry argon is necessary. The calibration method chosen was a positive-displacement method (see Figure 9). A tank of high-purity argon is connected through a pressure regulator and flowmeter to the inlet side of the Moisture Monitor Rotameter. The exit side is connected to the top of a 100-ml burette which is connected by rubber tubing to a separatory funnel open to the atmosphere. Both the burette and the funnel are filled with water. As the gas passes through the Rotameter into the burette displacing the water, the separatory funnel is made to move in such a way as to keep the water level in both the burette and the funnel at the same height. This allows the gas to replace the water in the burette without overcoming a head. Rate of flow is measured by timing the replacement of 100 cu cm of water from the burette. The proper reading on the Rotameter to give a flow rate of 100 cu cm per min of argon was measured to be 110 cu cm per min.

Figure 5.

Moisture Monitor

Picture taken from Moisture Monitor Operation and Maintenance Manual of Consolidated Electrodynamics Corporation.

Figure 9.
Rotameter Calibration Setup

The small pressure differential between the gases inside the glovebox and atmospheric pressure necessitates the use of a vacuum pump on the exit side of the Moisture Monitor. The meter works well under these conditions and has a response time approximately that claimed by the manufacturer. As initially set up, the moisture-measuring system had a shut-off valve at each end of the sampling tube. When this tube is left under vacuum over night, it tends to pick up moisture and bias the meter readings. When only the valve immediately in front of the Moisture Monitor is closed and the sampling tube is kept open to the glovebox, no moisture enters the tube and accurate readings are attained.

Sampling of the glovebox atmosphere for other contaminants is done by spectrographic examination of gaseous samples. A previously evacuated sample bottle, suitable for service on a spectrograph, is connected to a sampling outlet. The bottle is purged for one minute, sealed, and sent for analysis. Since any leak in the system is detectable with the Moisture Monitor, the atmosphere was sampled only once a week while the testing program was in progress.

E. Sealing and Startup of Glovebox System

The wear-testing machine, the balance, and the tools required to operate and maintain them were put in the glovebox and covered with sheet plastic. The electrical connections were made, the equipment tested, and the box sealed by closing the entrance port.

The large volume of the glovebox and the narrow range of pressures near atmospheric over which the box is leaktight makes the replacement of gas in the hood by purging very inefficient. Instead a more positive method involving plastic bags can be substituted. Two polyethylene weather balloons are placed inside the box and sealed to gas inlet tubes. This allows the balloons to be inflated from outside the box. After the glovebox is sealed, the balloons are inflated with helium, forcing the air out through the sampling outlet. When fully inflated, the balloons occupy from 80 to 85 per cent of the volume of the box. Next, the balloons are disconnected from the source of helium and the sampling outlet closed. Argon gas is admitted to the glovebox through the primary drying train, forcing the helium from the balloons. Repeating this displacement procedure three times removes almost all of the gas present in the glovebox at sealing.

Helium is preferred for inflating the balloons because it causes them to inflate from the top down. They drift to the top of the glovebox when partially filled and expand downward producing very little rubbing between balloon and box. When argon is used the balloons expand along the bottom of the box until forced upward. In rising they rub against the walls and can easily be punctured by projections such as bolt heads.

After the air initially present in the glovebox was displaced by argon gas, a period of about seven days was required to reduce the moisture level in the box to under 30 ppm.

EXPERIMENTAL PROCEDURE

A. General

Most of the samples tested were fabricated from stock furnished by commercial suppliers interested in wearability in atmospheres of low humidity. None had been tested in an atmosphere of high alpha and gamma activity, but most were materials known to be relatively unaffected by irradiation. Stock was received in the form of plates or rounds and test specimens were fabricated at ANL. One group of samples consisting of impregnated plastic coatings on SAE 1045 steel was made by having steel specimens, fabricated at ANL, coated by Electrofilm Incorporated of North Hollywood, California.

After machining, each sample measured 0.450 x 0.450 x 0.200 in. Much of the sample stock was fabricated by powdered metallurgy techniques and contained some void space, the amount varying from sample to sample. Because of this it was impossible to establish a uniform surface finish suitable to all samples. The sample stock also varied remarkably in physical properties. Some of the graphite derivatives were extremely hard and were fabricated by grinding while others were friable and had to be machined with a fly cutter. Whenever a supplier recommended a machining technique, it was followed and the resulting sample surface considered suitable. Thus each sample had a characteristic surface if not a similar one. Those samples which could be finished by several methods, such as metal alloys, were given a 10 RMS finish by grinding.* No attempt was made to contour sample wear surfaces to fit wear ring surfaces; thus contact between sample and wear ring was initially linear.

The wear resistance of each material is judged by measuring the average weight lost during a 24-hour abrasion period in which a group of two or three samples, fabricated from a single piece of stock, rub circumferentially against $2\frac{1}{2}$ -in. OD steel rings (SAE 1045). Each sample is removed from the test machine and weighed several times during the test. The weight lost by the samples from a single piece of stock are averaged and plotted to obtain the data given.

*The root mean square roughness height is 10 microinches.

B. Sample Preparation

Although the samples were machined without the use of a lubricant or coolant, the initial step in the preparation of most samples is degreasing. Samples made from metals or graphite derivatives are rinsed twice in trichlorethylene and twice in ethyl alcohol. The degreased samples are then put in an electric furnace and heated to 150°C for 30 minutes. While still hot they are put in open bottles in a vacuum desiccator and pumped on over night. The desiccator is back-filled with high-purity argon gas (99.9% A), opened, and the sample bottles sealed. Neither the plastic-coated nor the boron nitride samples can be degreased and the plastic-coated samples cannot be heated; however, all can be evacuated.

The sample bottles are then sealed into the transfer bag with a packet of Molecular Sieves. They remain sealed for 24 hours before the bag is cut open from inside the glovebox. No change in the moisture content of the atmosphere was detected by the Moisture Monitor when either the bag or the sample bottles were opened. All samples are exposed to the glovebox atmosphere for 24 hours before being tested.

C. Testing Machine Preparation

Before each group of samples is tested, the wear rings of the testing machine are resurfaced. The method chosen involves the use of a series of metallographic polishing papers. After initial grinding with coarse emery paper to remove the deeper imperfections, the rings are finished using 320 A, 400 A, and 600 A papers in that order. Papers are mounted on a suitable paddle and care exerted to keep all grinding marks peripheral. This particular technique was selected on the basis of ease of operation in a glovebox and the quality of surface produced. It is felt that the most reproducible finish is the best finish attainable under the conditions imposed. It became known early in the test program that surface finish is of extreme importance and that the samples can have a practicable longevity only if the surface against which they rub is as smooth as possible. After being resurfaced by this method, the rings have a finish approaching a polish.

D. Test Procedure

It was decided early in the program that all samples would be given a preliminary test at low load and low speed, and those found acceptable tested under more severe conditions. Initial tests conducted on graphite resulted in only a negligible loss in weight. Therefore, the testing conditions were changed to a load of 2755 gm (the maximum load attainable with the test machine) and a ring speed of 1000 rpm (109 ft per sec peripheral speed).

Testing of the graphite derivatives and metals initiates with the weighing of samples in the glovebox. After weighing the samples are mounted in the test machine, usually two groups of three samples each comprise a single loading, and the machine started. Next the load is applied and the speed control adjusted to achieve the appropriate speed. After accumulative test periods of 2 and 8 hours, the testing machine is turned off and the samples removed and weighed. The weights are recorded, the samples returned to the testing machine, and the test continued. All are returned to their original stations and no resurfacing of the wear rings is done during intermediate shutdowns. Care is taken to insure that samples are replaced as closely as possible to their original positions. Samples are seated on the rings before they are secured in the sample holders. After an accumulative test period of 24 hours, the samples are removed and weighed and the wear rings resurfaced for the next test. During the 24-hour test period each sample rubs over a linear distance of more than 942,000 ft, which is comparable in distance to more than 257,000 strokes of the longest pistons to be used (22-in. maximum travel).

The bulk of the samples tested were not irradiated because they were made of materials known to be unaffected by gamma irradiation. This is not the case for the plastic-coated steel samples. The impregnated plastic coating, which is expected to furnish the wear resistance, is known to be susceptible to structural changes under gamma irradiation; therefore, it is necessary to test these samples in both the irradiated and unirradiated conditions. Three groups of 10 identical samples each were furnished by Electrofilm Incorporated for testing. Two samples from each group were retained in the as-received condition and the remaining 8 subjected to gamma irradiation in the Gamma Irradiation Facility at ANL. The total dosage received by the individual samples of each group ranged from 1×10^6 to 99.8×10^6 rad.*

The criterion of loss in weight per unit time is not a suitable one for the coated samples because of the large difference between the density of the steel and the density of the plastic coating. Instead, the criterion of time to galling must be substituted. The wear surface of the coated samples is contoured to fit the wear rings to prevent the coating from being worn through in only one spot. The sample area in contact with the wear ring surface was 0.820 sq cm. As a preliminary test, two samples from each group were run using a load of 867 grams and a speed of 600 rpm (65 ft per sec peripheral speed). The test was complete when the plastic coating was worn through, as evidenced by galling of the wear rings. The two samples chosen from each group consisted of one of the as-received samples and the sample irradiated to a total dosage of 50.8×10^6 rad. Additional testing of the plastic-coated samples was found to be unnecessary, since neither the as-received or the irradiated sample lasted as long as the graphite derivatives.

*rad = 0.9128 roentgen

It is believed that the moisture content of the glovebox atmosphere remained below 30 ppm during the entire testing period. It is thought to have averaged approximately 10 ppm and reached a minimum of 3.6 ppm, as indicated by the Moisture Monitor. The concentration of other contaminants as determined by periodic spectrographic analysis is given in Table I.

Table I

CONCENTRATION OF GASES IN GLOVEBOX
ATMOSPHERE AS DETERMINED BY
PERIODIC SPECTROGRAPHIC
EXAMINATION

Constituent	Per Cent by Volume*		
	Max.	Avg.	Min.
A	99.8	98.5	96.4
N ₂	0.94	0.60	0.17
O ₂	0.18	0.13	0.04

*Remainder largely helium

EXPERIMENTAL RESULTS

A group of six Reactor Grade graphite samples was used to determine the degree of reproducibility of the testing procedure. The six samples were run on the six rings used in testing to determine the agreement between rings and rerun to determine reproducibility. For the rerun, the wear rings were resurfaced and a new sample surface used. No attempt was made to return the samples to their original stations for the rerun. The data obtained during the two runs is shown in Table II. There is an evident difference between the results obtained from the individual wear rings; however, the magnitude of the difference between extreme values is less than a milligram over the 24-hour test period. A difference of this magnitude is unlikely to be the basis of acceptance or rejection. There is also a difference in the average values of the two runs but it too is comparatively small. It is assumed that the difference in the weight lost by the samples at various stations, and in the individual runs, is the result of the test conditions prevailing at a given station during a given run; however, it is possible that a portion of these differences are due to the sample wear surface itself. In any case, the reproducibility between stations and between runs is considered sufficient for the application.

Table II
ACCUMULATIVE WEIGHT LOSS FOR
SAMPLES OF REACTOR GRADE
GRAPHITE*

Run No.	Station No.	Sample Loss (mg) during		
		2 hr	8 hr	24 hr
1	1	0.4	0.4	1.0
1	2	0.2	0.2	0.8
1	3	0.1	0.3	1.0
1	4	0.1	0.4	0.9
1	5	0.4	0.7	1.1
1	6	**	**	1.2
2	1	0.1	0.1	0.5
2	2	0.1	0.3	1.1
2	3	0.3	0.5	1.4
2	4	0.3	0.5	1.2
2	5	0.2	0.3	1.4
2	6	0.1	0.3	1.4

*Using load of 2755 gm and ring speed of 1000 rpm (peripheral speed of 109 ft per sec).

**Balance misread.

The data in Table III represents the results of tests on graphite derivatives and metals. The figures given are an average of results obtained on at least two samples tested simultaneously. The measured weight loss for individual samples was averaged for each group and plotted. The figures given are values taken from the graph. The volume loss, as calculated from the weight loss, for the 24-hour test period is also given. Account is taken of such special results as galling, marking of the wear rings, and high initial wear. This last point can be very important in choosing a material for use in a situation where the direction of rubbing is not constant.

The samples designated Reactor Grade graphite, 411, P5-AG, and High Cadmium all performed well under the conditions of the test. To make a selection between them, an elimination test was set up that is similar in all respects to the original test except for the condition of the wear ring surfaces. Rings are polished, as described previously, and

Table III

ACCUMULATIVE WEIGHT LOSS FOR GRAPHITE DERIVATIVE AND METALLIC SAMPLES**

Sample Designation	Supplier	Number of Samples Tested	Sample Loss (mg) during				Volume Loss (cm ³ x 10 ³)	Remarks
			2 hr	6 hr	12 hr	24 hr		
Reactor Grade Graphite	National Carbon Co.	6	0.2	0.3	0.6	1.1	0.66	Did not mark wear ring
P5-RAG	Pure Carbon Co.	4	0.3	0.8	1.0	1.3	0.54	
P658-RC	Pure Carbon Co.	4	*	0.3	0.4	0.7	0.40	
56-HT	Pure Carbon Co.	4	0.6	1.0	1.2	1.8	1.05	High initial wear
P5-N	Pure Carbon Co.	4	0.2	0.3	0.5	0.6	0.32	
111	Graphite Metallizing Corp.	4	*	0.1	0.2	0.5	0.18	
511	Graphite Metallizing Corp.	4	0.7	1.8	2.6	3.1	0.90	High initial wear
411	Graphite Metallizing Corp.	4	*	*	*	*	*	Excellent
15 x 11	Graphite Metallizing Corp.	4	15+	--	--	--	--	Scored ring severely
3115	Graphite Metallizing Corp.	3	1.3	1.3	1.4	1.8	0.76	High initial wear
P5-AG	Pure Carbon Co.	3	*	0.1	0.2	0.3	0.12	Excellent
BIN	Electro-Nite Carbon Co.	4	0.4	1.1	3.1	10.1	6.73	High wear
211H	Electro-Nite Carbon Co.	4	0.8	1.6	2.3	3.6	2.26	High initial wear
Graphitar 1	U.S. Graphite Co.	3	--	--	--	--	--	High wear and galling
High Silver	Carbone Corp.	3	0.6	1.1	1.4	1.6	0.62	High initial wear
High Cadmium	Carbone Corp.	3	0.1	0.1	0.2	0.4	0.14	Excellent
High Bronze	Carbone Corp.	3	1.1	1.4	1.8	2.3	0.81	High initial wear
High Babbitt	Carbone Corp.	3	0.2	0.5	0.6	0.8	0.31	
P5721	Carbone Corp.	3	0.1	0.2	0.4	0.8	0.46	
AP7345	Carbone Corp.	3	125+	--	--	--	--	High wear and galling
75	U.S. Graphite Co.	3	0.9	3.5	11	25	1.78	
4	U.S. Graphite Co.	3	--	--	--	--	--	Galled ring severely
80	U.S. Graphite Co.	3	*	0.2	0.5	1.1	0.58	Low initial wear
3	U.S. Graphite Co.	3	1.0	1.6	2.1	3.0	1.70	High initial wear
67	U.S. Graphite Co.	3	0.3	0.6	0.8	1.3	0.74	
34	U.S. Graphite Co.	3	1.3+	--	--	--	--	Very high wear
2	U.S. Graphite Co.	3	0.8	1.5	1.7	1.8	1.00	High initial wear
Oilite	On hand	2	3.8+	--	--	--	--	Scored ring
Leaded Bronze	On hand	2	300+	--	--	--	--	Severe galling
Aluminum Bronze	On hand	2	134+	--	--	--	--	Severe galling

*Loss in weight not measureable

**Using load of 2755 gm and ring speed of 1000 rpm (peripheral speed of 109 ft per sec).

--Measurement not taken. Test discontinued.

then roughened with 320 A polishing paper. The results of the elimination test (see Table IV) show Reactor Grade graphite and the sample designated P5-AG to be superior under these conditions and indicate Reactor Grade graphite to be best.

Table IV

ACCUMULATIVE WEIGHT LOSS OF SAMPLES
DURING ELIMINATION TEST*

Sample Designation	Sample Loss (mg)		Volume Loss ($\text{cm}^3 \times 10^3$)	Remarks
	2 hr	24 hr		
Reactor Grade Graphite	0.2	0.5	0.30	Least damaging to wear rings
411	224+	-	-	Sample wore down in 5 min
P5-AG	0.1	1.4	0.54	
High Cadmium	9.5	10.2	3.47	High initial wear

*Wear rings roughened with 320A metallographic polishing paper.

Teepelite 1, a bearing material furnished by the Crane Packing Company, and boron nitride were tested, using a load of 867 gm and a speed of 600 rpm. The boron nitride samples disintegrated very quickly and the Teepelite samples lost more than 7 mg each during the 24-hour test period.

The results of the test of plastic-coated steel samples are given in Table V. Using a load of 867 gm and a ring speed of 600 rpm, the maximum sample life was approximately 20 hours. It appears that the useful life expected from coated materials is less than from graphite. It should be noted that irradiation did not reduce the useful life of the coated specimens. The samples designated 4396 rubbed over a linear distance equivalent to more than 128,000 strokes of the longest piston to be used. Since the coated samples can be readily made to very close tolerances by Electrofilm Incorporated, they may merit consideration as piston seals.

Table V

LIFE OF PLASTIC-COATED
STEEL SAMPLES*

Sample Designation	Total Irradiation (rad)	Time to Galling (hr)
66-C-1	None	1.0
66-C-5	50.8×10^6	7.0
77-S-11	None	2.5
77-S-15	50.8×10^6	13.6
4396-21	None	19.2
4396-25	50.8×10^6	20.9

*Using load of 867 gm and ring speed of 600 rpm (peripheral speed of 65 ft per sec).

DISCUSSION

The samples designated Reactor Grade graphite, P5-AG, High Cadmium, 411, and 111 appear to have at least as good bearing qualities as the other samples tested under the conditions described. Reactor Grade graphite appeared to be least damaging to the wear rings. The steel samples coated with impregnated plastic do not appear to be as good as the better graphitic samples; however, for many uses, they may be superior physically and they do not appear to be deleteriously affected by the gamma irradiation to which they were exposed.

The most important single factor in determining the life of a graphitic sample appears to be the roughness of the surface against which it rubs. Sample behavior suggests the presence of a film on at least a portion of the sample surface which has good wear resistance. When this film is destroyed, the sample loses weight rapidly. It should be mentioned that the Gast pump ran continuously for a period of over a month with no great damage to its graphitic vanes after a run-in period in a wet atmosphere.