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MEASUREMENT OF THE WEAR RATE OF CAST GRINDING BALLS USING RADIOACTIVE TRACERS

by

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MINERAL SCIENCES DIVISION

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J.D. Keys* and G.G. Eichholz**

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SYNOPSIS

The wear rate of grinding balls is usually difficult to determine under operational conditions, and little is known about the factors determining ball life. Radioactive tracers have been used successfully to mark cast steel balls to obtain information on their life under various operating conditions, in comparison with balls of different type or composition. A batch of marked steel balls has been followed through a mill operation over several weeks, and statistics on wear and loss of weight have been obtained.

In earlier test runs using Fe^{59}, techniques were established and qualitative observations made on wear rate. In the present experiments, Co^{60} was used as the tracer, which was added to the molten metal prior to casting. The cast balls were used in a mill at an iron mine. The radioactive batch was added to the ball mill which had a normal charge of about 77.3 tons (metric). The charge was sampled at weekly intervals to pick out some of the radioactive balls. These balls were inspected and weighed, and the wear rate has been calculated. This procedure has proved to be a practical way of investigating grinding behaviour under plant operating conditions.

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Bulletin Technique de la Direction des Mines TB 18

MESURE, PAR RADIOINDICATEURS, DU COEFFICIENT D'USURE DE BOULETS-BROYEURS COULÉS

par

J. D. Keys* et G. G. Eichholz**

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RÉSUMÉ

Il est ordinairement difficile de déterminer le coefficient d'usure de boulets-broyeurs dans les conditions mêmes où ils servent, et on sait très peu de choses des facteurs qui en déterminent la durée. Au moyen de radioindicateurs, on a réussi à individualiser des boulets coulés pour obtenir des renseignements sur leur durée dans diverses conditions d'utilisation en comparaison de boulets de type ou de composition différents. On a surveillé un lot de boulets d'acier marqués, pendant plusieurs semaines de service dans une usine; il a été ainsi possible d'établir la statistique d'usure et de perte de poids.

Au cours d'essais précédents portant sur Fe^{59}, on avait mis au point des techniques et fait des observations qualitatives sur le coefficient d'usure. Cette fois-ci, on s'est servi, comme indicateur, de Co^{60} qui avait été ajouté au métal en fusion avant le coulage. Les expériences ont eu lieu dans l'atelier d'une mine de fer: on a ajouté les boulets radioactifs dans un moulin à boulets portant une charge moyenne d'environ 77.3 tonnes métriques. Une fois par semaine, on prélevait des échantillons de la charge pour retrouver un certain nombre de boulets radioactifs, afin de les examiner et de les peser. On a ainsi calculé leur coefficient d'usure. Cette expérience s'est révélée très utile pour étudier le comportement des boulets dans les conditions d'utilisation industrielle.

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INTRODUCTION

The wear rate of steel grinding balls in cylindrical ball mills has been the subject of several investigations during the past forty years. The conclusions and theories resulting from these studies differ considerably, partly because of the difficulty of following a batch of grinding balls through an actual mill operation. This difficulty can be eliminated by the use of grinding balls tagged with radioactive tracers. In this way, data on wear rates can be obtained in a relatively short time under operating conditions. Special test mills, or many years of observation, would normally be required to obtain this same information.

The first attempt to formulate a theory of ball wear in cylindrical mills was made by Davis (1) in 1919. He concluded that the rate at which the weight of any ball decreases is directly proportional to its weight. His results appear to have been accepted until 1940 when Bond (2) reported, on the basis of nine years of observations, that "a film of any specified thickness is worn from a large ball slightly faster than from a small ball in the same charge". This conclusion was modified in 1943 by Prentice (3) who, after carrying out extensive tests in a laboratory-size mill, postulated that the rate of decrease in diameter of a ball is constant as long as the ball remains of sufficient size to contribute to the grinding process. Later investigations (4, 5, 6, 7) have confirmed Prentice's hypothesis and it is now accepted that balls used under identical conditions will lose a surface layer of equal thickness, regardless of size; i.e., the loss in weight is proportional to the square of the diameter.

EXPERIMENTAL METHOD

In performing tests to determine wear rate, the problem has been to trace the history of a given batch of balls. Using a small-scale mill, of nominal diameter 30 in. (76 cm) and length 18 in. (46 cm), Prentice employed two methods. One involved drilling holes in a particular batch of balls and sorting these balls at weekly intervals by inspection. The other made use of the fact that, if balls were added only at weekly intervals to the charge in the mill, there was sufficient wear in one week to enable differentiation of the various batches. The first of these methods was not satisfactory, as in some cases the holes caused the balls to wear abnormally. The second method, while applicable to a laboratory-size mill, is not practical for a full-scale operating mill.

The present investigation utilized cast balls tagged with a radioactive isotope. Previous experiments (8) had established a practical procedure for introducing the radioactive metal into the melt. Suitable precautions were also taken for dealing with health hazards arising in the course of the work. In those tests Fe^{59} was used to label the balls which were then measured to check comparative wear rates, in a qualitative manner only, in two mills, one treating iron ore and the other a gold-bearing ore. In the present investigation, the intention was to obtain quantitative information on the relative wear rate of cast balls compared with forged balls, under given mill conditions. Co^{60}, because of its long half-life and ready availability, was used as a tracer in these tests.

Experience has shown (3) that as a ball is worn down it becomes less spherical, with flats developing. It has been postulated that the small shapes become lodged in the interstitial positions between the large balls and do not contribute to the grinding action (3). In addition, when the balls acquire these odd shapes they tend to break up into small pieces and, as such, are subject to comminution along with the ore rather than remaining as part of the grinding medium. In view of these effects there is a lower limit--approximately 3/4 in. (1.9 cm) diameter--below which no useful information concerning the wear rate may be obtained. The results contained herein are presented in accordance with these considerations.

EXPERIMENTAL PROCEDURE

The balls employed in these tests were cast by Neelon Steel Ltd., Sudbury Junction, Ontario, Canada. Data concerning the physical and metallurgical characteristics of the balls are given in Table 1.

TABLE 1

Grinding Ball Data

Ball composition:		
Carbon	0.65 - 0.75%	
Manganese	0.45 - 0.55%	
Silicon	0.40 - 0.50%	
Sulphur	0.050% max.	
Phosphorus	0.050% max.	
Chromium	0.90 - 1.10%	
Molybdenum	0.15 - 0.20%	
Average weight of balls	1.2 lb	550 g
Nominal diameter of balls	2 in.	5 cm
Specific gravity of balls	7.6	
Hardness of balls	450-500 Brinell	

Prior to casting, 50 mC of Co^{60} were added to the molten metal, which weighed roughly 5½ tons (metric). From this, approximately 6,000 suitable balls, each containing 5 μC Co^{60}, were obtained. These were added over a 24-hour period to the charge of a cylindrical ball mill at the iron mine of Lowphos Ore Ltd., Capreol, Ontario. The normal ball charge of this mill is 77.3 tons (metric). During the weekly inspection one to two per cent of the radioactive balls were located, washed, dried, and weighed. Each week this operation was repeated, the mean weight determined for the sample, and the successive values plotted as a function of time.

In the method employed in this investigation, no difficulty was experienced in tracing the particular batch of balls through their life. The "down time" of the mill was no longer than was required for normal inspection purposes, and the charge was maintained at its operating level by the regular addition of untagged balls of 2 in. (5 cm) diameter.

Table 2 presents information regarding the ball mill in which the actual tests were done.

TABLE 2

Ball Mill Data

Diameter of ball mill	11.5 ft (3.5 m)
Length of ball mill	14 ft (4.3 m)
Speed of rotation	18 r.p.m.
Per cent of critical speed	75%
Moisture	25-30% by weight
Mill liner is Ni-hard ship-lap with high edge leading.	

EXPERIMENTAL RESULTS

It is customary, in ball-milling, to express wear rate either as the weight of balls consumed per ton of ore milled or as the weight of balls consumed per unit time of operation. However, in the present case information concerning wear rate is given, in Table 3, in terms of both the tons milled and the total operating time.

The values listed in Table 3 for the mean ball weight were obtained by taking the arithmetic mean of the samples withdrawn each week. Each mean weight represents the average of between fifty and one hundred balls. The weekly distributions of ball weights from which the means were obtained are shown in the frequency histograms of Figures 1 and 2. It should be noted that the weights of the balls added to the mill were not identical, but were assumed to be distributed about the mean according to a normal law.

TABLE 3

Mean Ball Weight, Cumulative Operating Time, and Cumulative Tons Milled

Week No.	Mean Ball Weight (g)	Cumulative Operating Time (hr)	Cumulative Tons Milled (metric tons)
1	509.4	118.6	5780
2	469.5	276.4	14100
3	427.9	434.0	21400
4	410.1	591.1	28900
5	345.6	752.1	35900
6	299.0	901.7	43500
7	273.3	1040.0	49800
8	235.4	1203.6	57200
9	221.0	1358.0	64100
10	185.8	1514.1	70600
11	167.4	1671.2	77100
12	133.6	1832.4	86200

DISCUSSION OF RESULTS

Prentice's theory, that the rate of reduction of ball diameter is constant, may be expressed by

$$\frac{-dD}{dt} = C \qquad \ldots.1)$$

where D is the diameter of the ball and C is a constant for a given type of ball in a given mill. Expressed in terms of weight loss, equation (1) becomes

$$\frac{-dm}{dt} = \text{constant x } D^2 \qquad \ldots.2)$$

This leads to a relationship between the weight at the beginning of the test m_o and the weight m at a given time t later, expressed by

$$m^{1/3} = -c' t + m_o^{1/3} \qquad \ldots.3)$$

where c' is another constant.

If $m^{1/3}$ is plotted against t a straight line should result. Such a plot is shown in Figure 3, from which it may be seen that the expected relationship does indeed exist.

The mean weight of the balls withdrawn after a running time of 591 hours showed an abnormally small standard deviation and some departure from a normal distribution. For this reason, the corresponding point on the curve of Figure 3 was not given as much statistical weight as were the other points.

The straight line of Figure 3 is the best fit obtained by a least squares analysis. The fluctuations about the mean are greater than might be expected in view of the size of sample obtained for each point. These fluctuations are attributed to the fact that in this mill the ore feed varies in hardness from Bond work index 18 to 27. Although Table 3 shows that the tonnage milled each week is not constant, there is little evidence to support a theory that "the less the ore milled, the greater the wear".

During the sampling period, attention was paid to the location of the marked balls in the mill and, in particular, to any evidence of size segregation. There was no indication in this operation that segregation had occurred, either along the mill or in cross-section. Furthermore, the balls retained their spherical shape for the greater part of their life, until the diameter was less than 0.8 in. (2 cm).

There appears to be ample confirmation in the literature for Prentice's theory of ball wear. However, the bulk of experimental results has come from mills in which the maximum diameter of the balls charged is from 3.5 in. (9 cm) to 4 in. (10 cm). Far less information has become available for mills where 2 in. (5 cm) diameter balls have been the largest added. This was presumably due to the difficulty of following a given batch through the entire operation with complete assurance as to the identity of the test balls. With the method employed in the present investigation it is possible to obtain a good statistical sample and to follow the "tagged" balls until they have been completely destroyed by attrition.

SUMMARY

1. A method of following a batch of cast grinding balls through its serviceable mill life, using a radioactive tracer, has been employed. This method provides a quick and simple means of obtaining a good statistical sample without prolonged shut-down of the mill operation.

2. On the basis of results obtained in the mill of Lowphos Ore Ltd., using balls of 2 in. (5 cm) diameter and not employing ball rationing, the law

$$\frac{-dD}{dt} = \text{constant}$$

was found to give the best fit.

3. It is proposed to use the same technique in future tests, as a means of a) determining the best composition of grinding ball for a particular operation, and b) obtaining additional information on the wear rate of cast balls in cylindrical ball mills.

ACKNOWLEDGMENTS

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The co-operation of Lowphos Ore Ltd. in whose mill the results were obtained was greatly appreciated. The authors would like to thank Mr. K.D. Conroy, the assistant mill superintendent, for his valuable contributions in the practical aspects of this work.

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JDK:GGE/DV

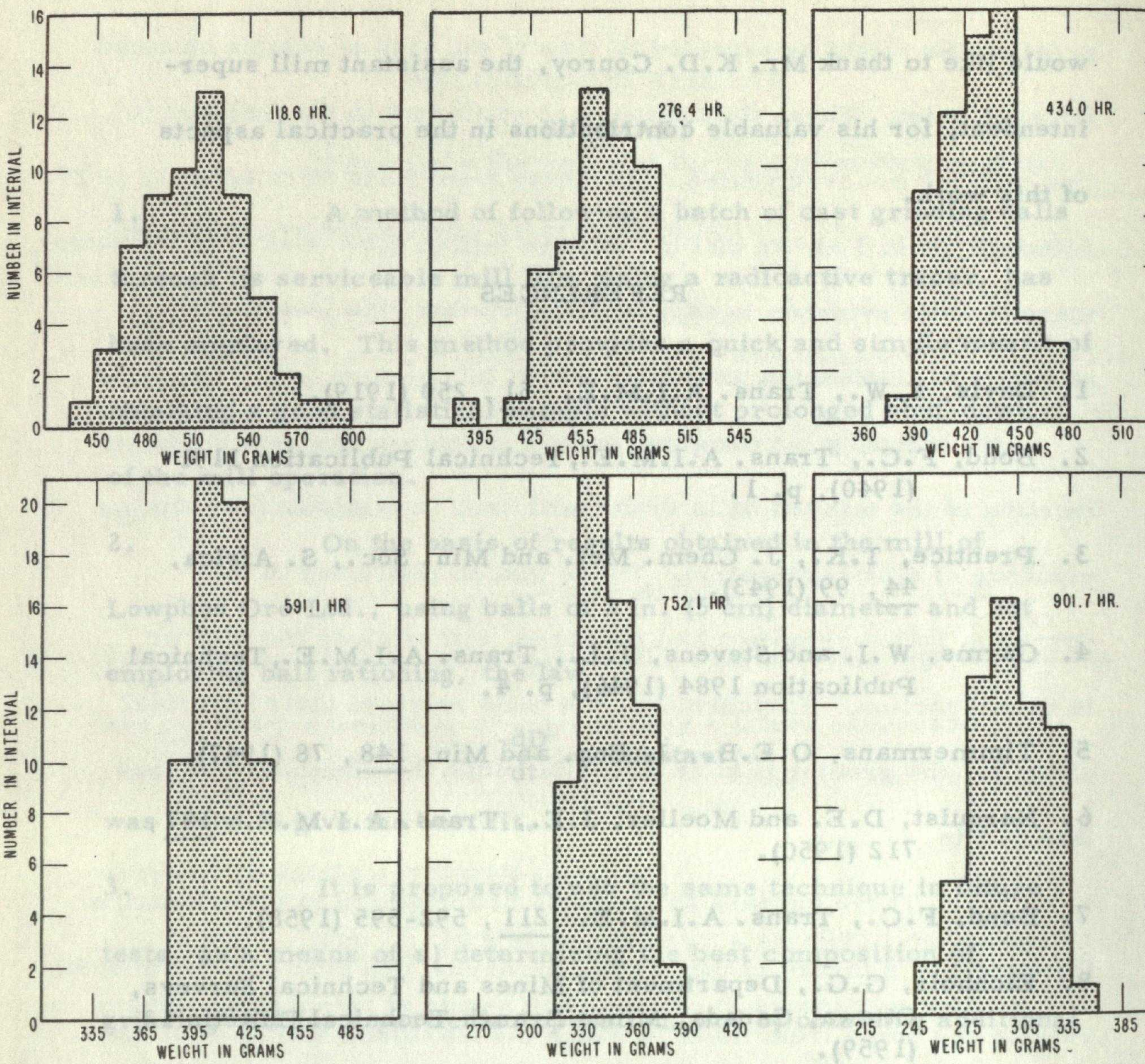

FIG. 1 - BALL WEAR HISTOGRAMS

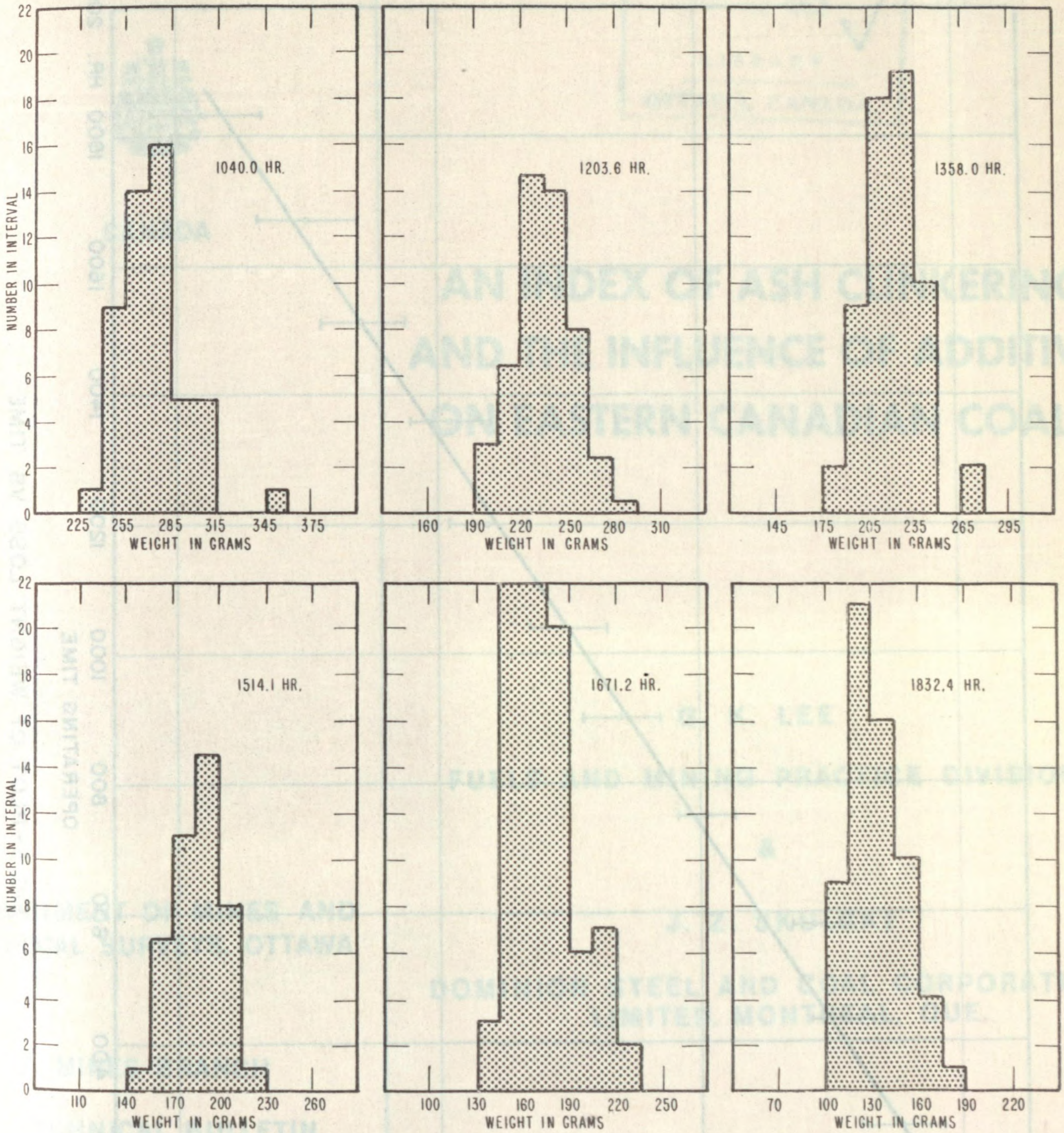

FIG. 2 - BALL WEAR HISTOGRAMS

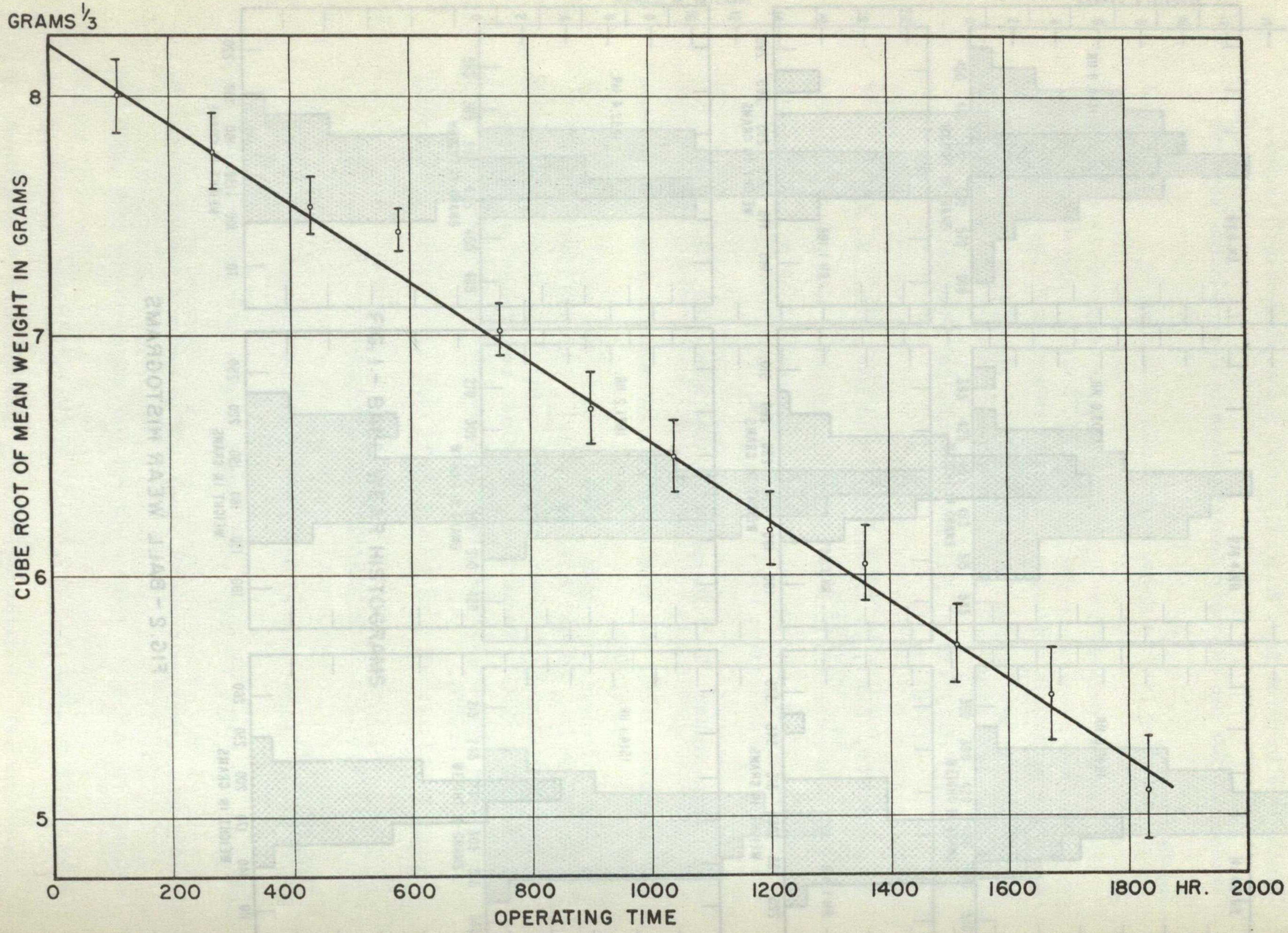

FIG. 3-PLOT OF WEIGHT LOSS VS TIME.