ORNL-3512
UC-25 – Metals, Ceramics, and Materials
TID-4500 (22nd ed.)

INSTRUMENT FOR DETERMINING CRUSHING STRENGTH OF PARTICLES

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OAK RIDGE NATIONAL LABORATORY
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Contract No. W-7405-eng-26

Metals and Ceramics Division

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Date Issued
NOV 29 1963

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Abstract

An instrument for crushing-strength determinations of uncoated and pyrolytic-carbon-coated fuel particles (50 to 500 μ in diameter) has been developed to relate the crushing strength of the particles to their fabricability. The instrument consists of a loading mechanism, load cell, and a power supply-readout unit.

The information that can be obtained by statistical methods of the data analysis is illustrated by results on two batches of fuel particles.

Introduction

Individually coated uranium carbide spheroids (50 to 500 μ in diameter) dispersed in graphite matrices are being considered as fuel element cores for gas-cooled and other high-temperature reactors. The spheroids are coated with pyrolytic graphite to retard the escape of radioactive fission products into the reactor system and to simplify handling of the material during fuel element fabrication.

Routine examinations to determine the properties of fuel particles include density measurements, metallographic examinations[1] of both the fuel particle and coating, metallography and microradiography to determine the coating thickness and fuel particle diameter, x-ray diffraction

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[1]C. K. H. DuBose and R. J. Gray, "Metallography of Pyrolytic Carbon Coated and Uncoated Uranium Carbide Spheres," USAEC Report ORNL-TM-91 (March 21, 1962).

analyses, and spectrographic analyses for qualitative identification of principal impurities. In addition, a need arose for determining the crushing strength of the fuel particles in order that the crushing strength could be related to their fabricability.

This report describes the design of an instrument for determining the crushing strength of fuel particles along with some experimental results to show its applicability.

Description of Instrument

The instrument for determining the crushing strength of fuel particles consists of a loading mechanism, load cell, and a power supply-readout unit. Figure 1 is a photograph of the equipment, including a lamp with a magnifying glass to aid in placing the fuel particle for testing.

Loading Mechanism

The loading mechanism permits low rates of load application on the fuel particle. A schematic drawing of the mechanism is shown in Fig. 2. The brass plate supports the load cell, a reversible fractional-horsepower motor, and a micropositioner.[2] The micropositioner has been modified to contain a fully hardened tool-steel compression rod which makes a contact with the fuel particle when the load is applied. The fine adjustment knob of the micropositioner is connected to the motor by means of a rubber belt. The motor drives the compression rod at an estimated rate of 0.2 mm/min; the slow motion is necessary to avoid impact of the rod on the particle.

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[2]Available from Brinkmann Instruments, Inc., Great Neck, New York.

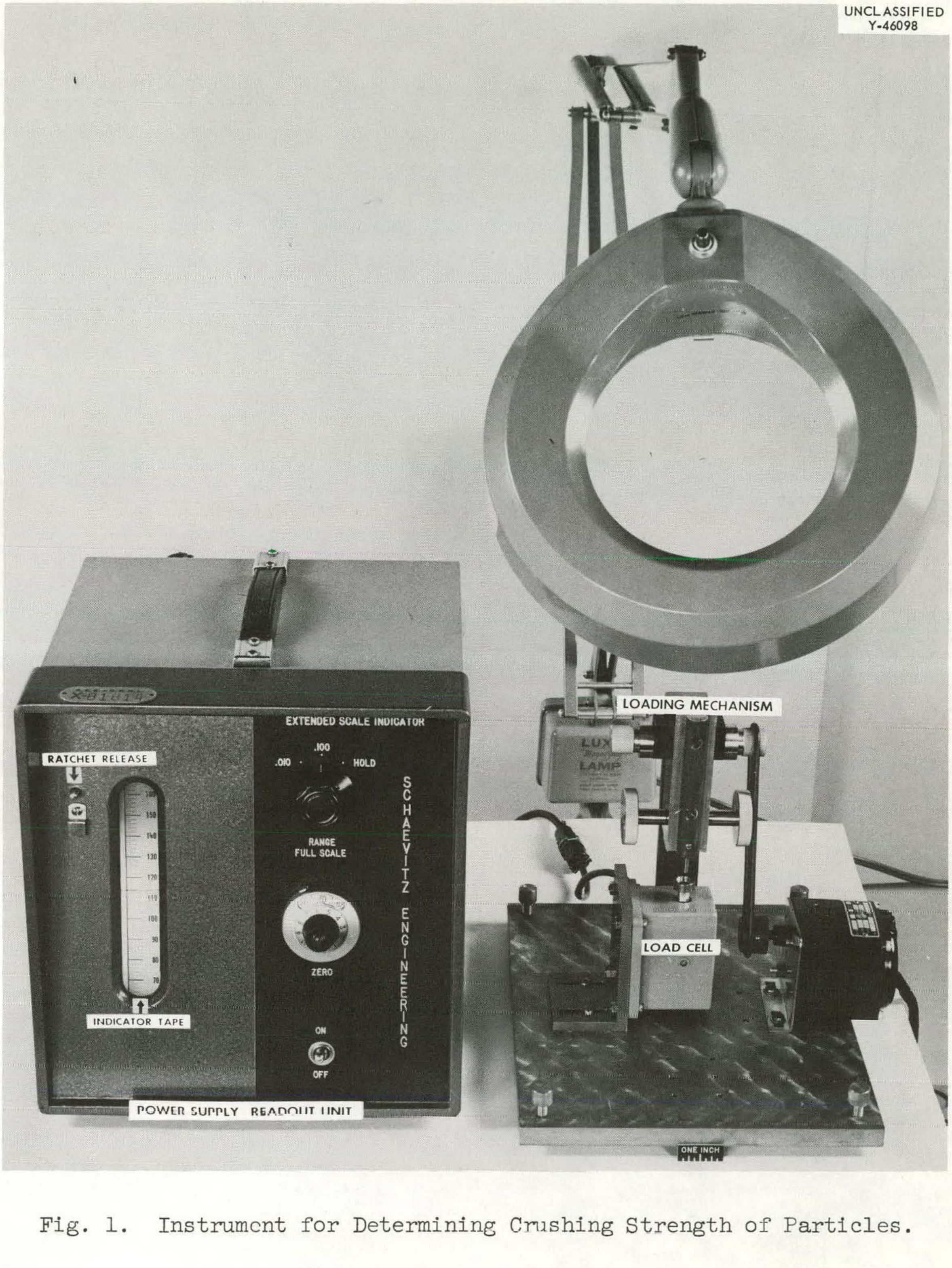

Fig. 1. Instrument for Determining Crushing Strength of Particles.

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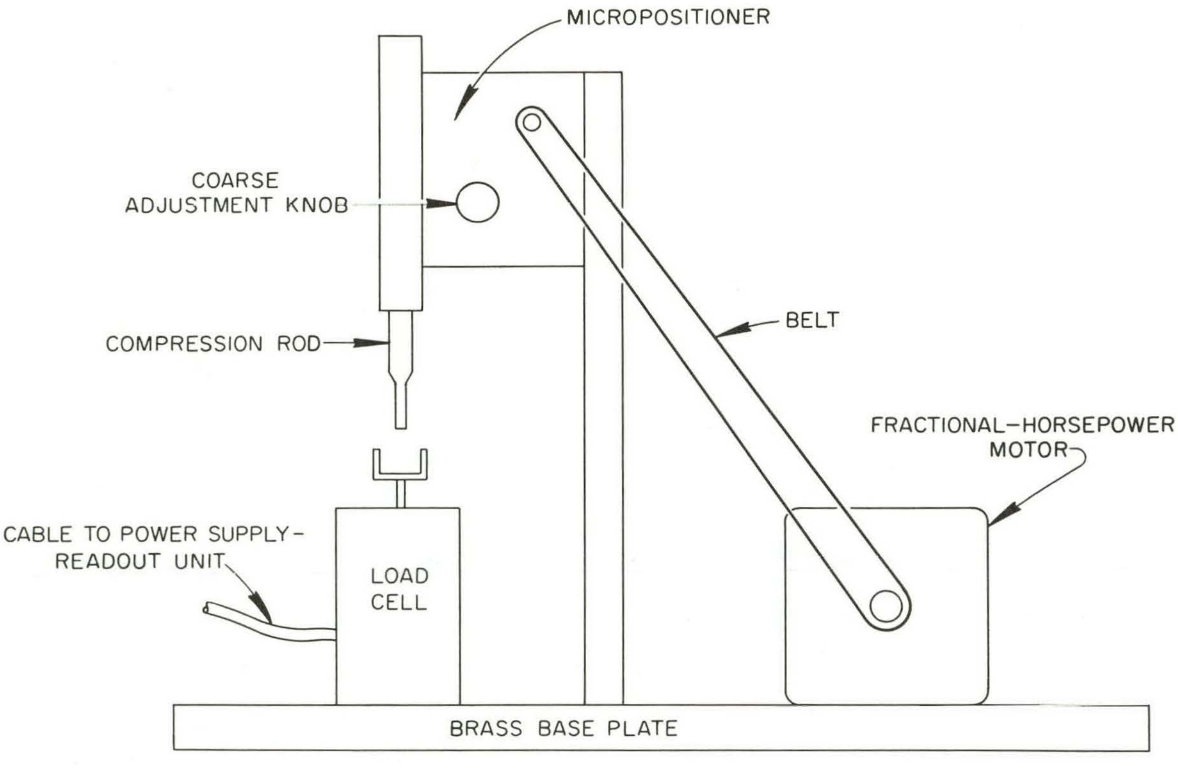

Fig. 2. Schematic Drawing of the Loading Mechanism.

Load Cell

The load cell,[3] shown schematically in Fig. 3, provides accurate and sensitive compressive-force measurements within a load range of 0 to 5 kg. It consists of a frame which supports a differential transformer, with an input voltage of 6.3 v at 60 cps supplied by the power supply-readout unit, and a transformer core suspended between two beams. Extending through the frame is a transformer core rod with a compression anvil. The anvil, like the compression rod of the micropositioner, is made of fully hardened tool steel. A brass ring is press-fitted around the anvil to prevent the scattering of the shattered fragments of the crushed particle.

The force applied to the anvil causes the deflection of the beams and with it the displacement of the transformer core relative to the position of the coils of the differential transformer. The output voltage caused by the displacement of the core is proportional to the deflection of the beams and to the magnitude of the applied force.

Power Supply-Readout Unit

The power supply-readout unit energizes the primary coil of the differential transformer in the load cell and displays the output voltage of the secondary coils on a 50-in.-long indicator tape. The moving tape follows continuously the deflection of the load cell beams during load application. A ratchet mechanism has been added to the indicator to lock the tape in the maximum position when the particle fractures under load. The indicator tape returns to the initial position when the ratchet release button, shown in Fig. 1, is depressed.

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[3]Both the load cell and the power supply-readout unit are available from Schaevitz Engineering, Camden, New Jersey.

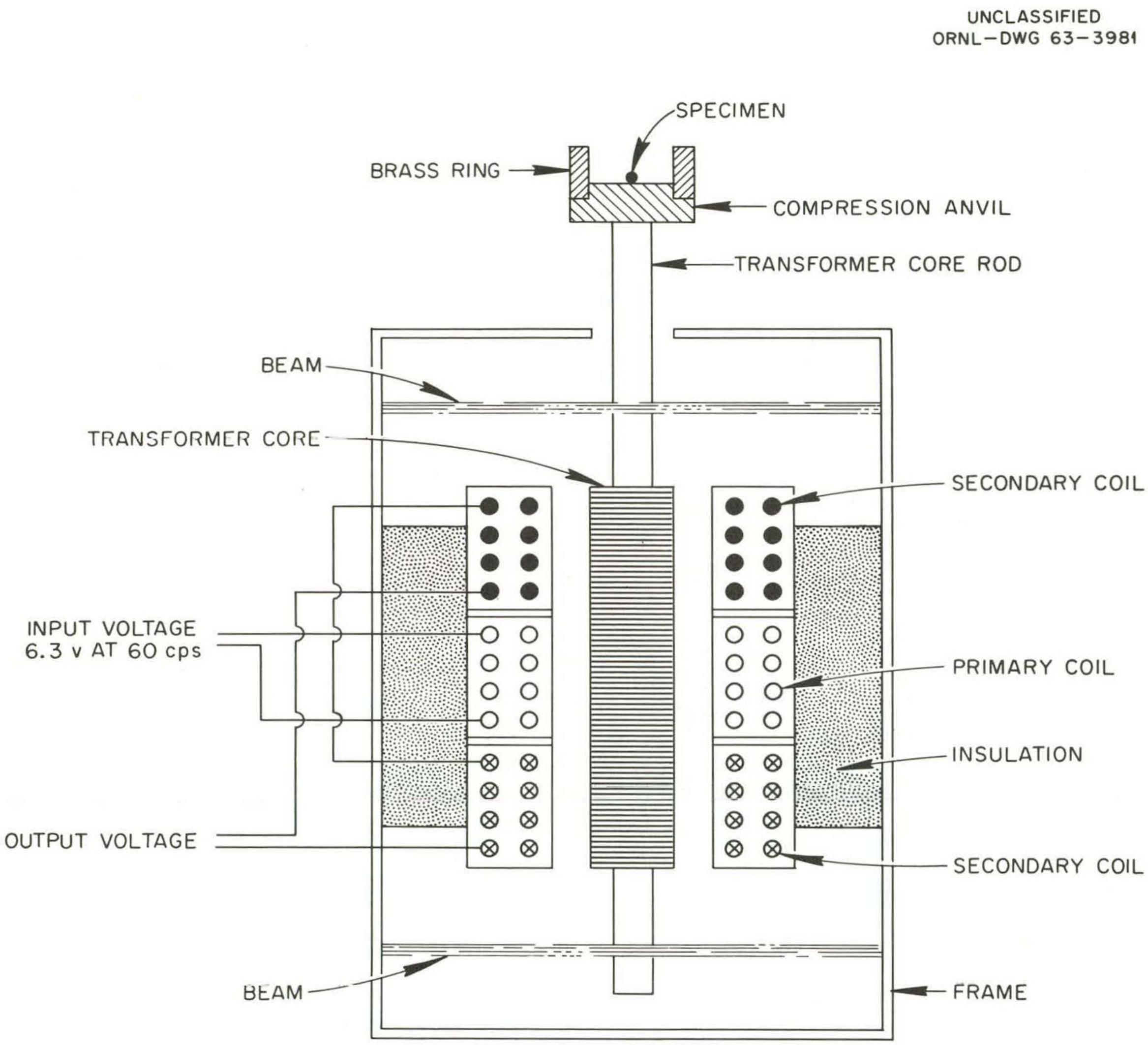

Fig. 3. Schematic Drawing of the Load Cell and Compression Anvil.

Calibration

With the compression anvil and the brass ring placed on the transformer core rod, the position of the differential transformer core relative to the transformer coils is adjusted by means of a null adjustment screw located on the body of the load cell. The null position is reached when the output voltage displayed by the indicator tape is minimum. The tape is then set to zero by means of a ten-turn precision potentiometer on the power supply-readout unit.

To check the linearity of the load cell and the indicating mechanism, a series of standard weights ranging from 10 to 4000 g is placed on the compression anvil. The reading of the tape plotted as a function of the applied weight shows that the linearity of both the load cell and the indicator is within ±1% in the range of loads under consideration.

In addition, a quick check of the calibration is made frequently by placing a single weight on the anvil and comparing the indicated value of the tape with the value obtained during the original calibration. After approximately 1500 particles were crushed, no recalibration was necessary.

Testing Procedure

A quick calibration check described above is always made prior to actual testing. An individual particle of the type shown in Fig. 4 is then placed near the center of the compression anvil, the compression rod is lowered manually by means of the coarse adjustment knob and, finally, the motor is turned on to continue slowly the downward motion of the rod. While the load is applied, the indicator tape moves continuously until the particle is crushed and the ratchet mechanism locks the tape in its maximum position. A reading of the tape then may be conveniently made. For crushing of the next sample, the compression rod is moved upward and the anvil is removed, cleaned, and replaced on the transformer core rod. It is possible to process 100 particles per day with this arrangement.

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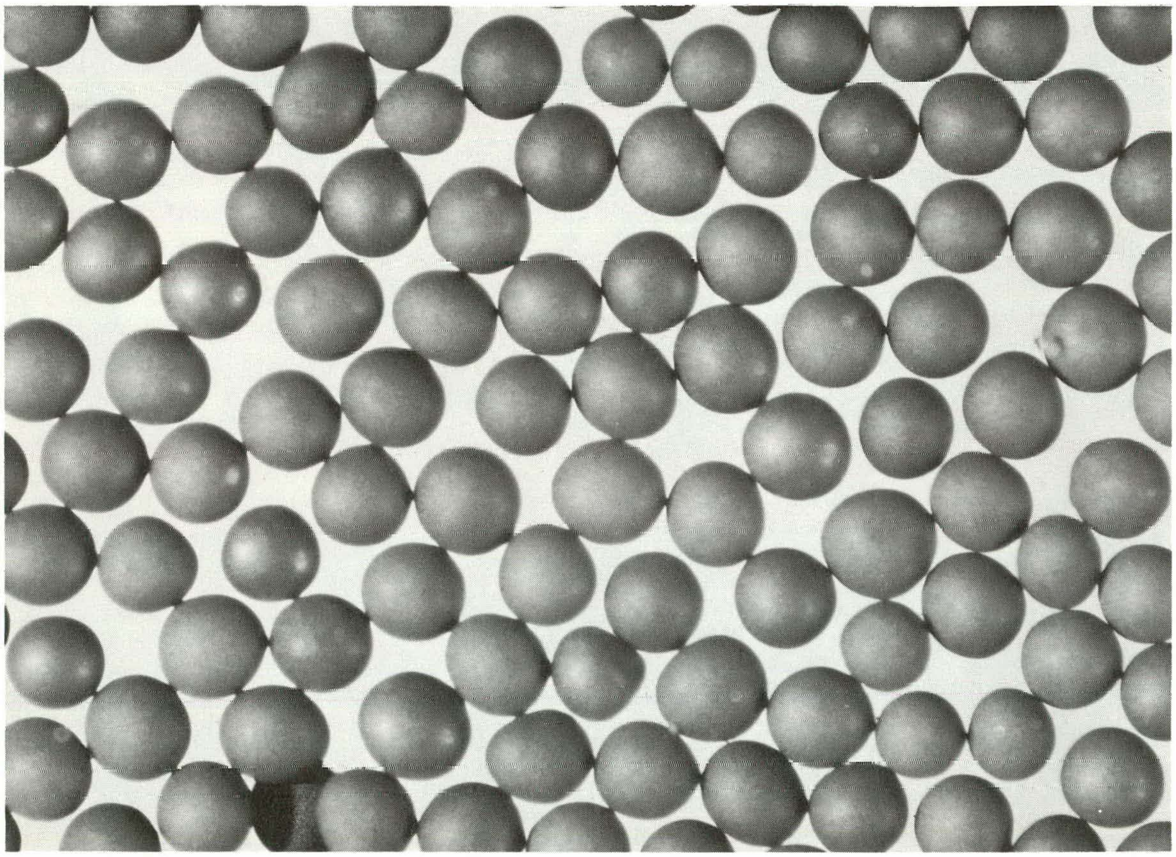

Fig. 4. Pyrolytic-Carbon-Coated Uranium Carbide Particles. 33X.

With the aid of the calibration curve, the reading obtained from the indicator tape is readily converted to a value of load required to crush an individual particle.

Statistical Considerations

The nature of the crushing-strength test requires the application of statistical methods to the analysis of the data. The tests are performed by crushing individual coated and uncoated fuel particles from a randomly selected sample of 50 particles from each batch.

Initially, the arithmetic mean of the crushing strength, the standard deviation, and the test for normality of the distribution were calculated manually. These calculations, however, were found to be time-consuming. Subsequently, a statistical code was programed for the IBM-7090 computer to speed the process of statistical calculations.

Results

The data obtained from crushing-strength determinations can be summed in two statistics, assuming a normal distribution.

The arithmetic mean of the crushing load is

$$X^1 = \left(\sum_{i=1}^{N} X_i \right) \Big/ N$$

where

N = number of crushing-strength determinations and

X_i = any one of these determinations.

The standard deviation is

$$S = \left[\frac{\sum_{i=1}^{N} (X_i - X^1)^2}{N - 1} \right]^{1/2} .$$

Table 1 compiles the crushing-strength data for the first two batches of samples tested. The calculated mean was 667 g and the standard deviation was 70 g for batch A; for batch B, the respective values were 858 and 113 g.

Table 1. Crushing Load of Fuel Particles

Batch A				Batch B			
No.	Crushing Load (g)	No.	Crushing Load (g)	No.	Crushing Load (g)	No.	Crushing Load (g)
1	790	26	695	1	832	26	1018
2	677	27	659	2	802	27	1066
3	587	28	707	3	689	28	647
4	605	29	707	4	1030	29	826
5	611	30	569	5	790	30	898
6	647	31	635	6	958	31	754
7	587	32	659	7	766	32	838
8	730	33	760	8	862	33	766
9	730	34	707	9	874	34	748
10	689	35	707	10	868	35	946
11	766	36	569	11	850	36	808
12	838	37	509	12	880	37	910
13	611	38	563	13	659	38	952
14	655	39	742	14	796	39	886
15	695	40	778	15	659	40	760
16	742	41	671	16	718	41	1030
17	647	42	671	17	844	42	910
18	635	43	695	18	587	43	868
19	647	44	581	19	910	44	982
20	802	45	659	20	940	45	826
21	659	46	689	21	808	46	853
22	659	47	701	22	1006	47	838
23	533	48	689	23	1108	48	886
24	617	49	623	24	946	49	1024
25	569	50	635	25	850	50	856

The crushing-strength data may also be plotted cumulatively on a normal probability paper, again assuming normal distribution. The crushing strength, the frequency of occurrence, and cumulative percent for the two batches of fuel particles are compiled in Table 2. In Fig. 5 the standard deviation, S, is estimated as the range between loads below which 50 and 85% of all samples have failed under the compressive load.

Table 2. Cumulative Percent of Crushing Loads

Batch A				Batch B			
Crushing Load (g)	Frequency	Frequency (%)	Cumulative (%)	Crushing Load (g)	Frequency	Frequency (%)	Cumulative (%)
510	1	2	2	590	1	2	2
530	1	2	4	650	1	2	4
570	4	8	12	660	2	4	8
580	1	2	14	690	1	2	10
590	2	4	18	720	1	2	12
610	3	6	24	750	2	4	16
620	2	4	28	760	1	2	18
640	3	6	34	770	2	4	22
650	3	6	40	790	1	2	24
660	5	10	50	800	2	4	28
670	3	6	56	810	2	4	32
680	1	2	58	830	3	6	38
690	3	6	64	840	3	6	44
700	4	8	72	850	3	6	50
710	4	8	80	860	2	4	54
730	2	4	84	870	4	8	62
740	2	4	88	880	1	2	64
760	1	2	90	890	1	2	66
770	1	2	92	900	1	2	68
780	1	2	94	910	3	6	74
790	1	2	96	940	1	2	76
800	1	2	98	950	3	6	82
840	1	2	100	960	1	2	84
				980	1	2	86
				1010	1	2	88
				1020	2	4	92
				1030	2	4	96
				1070	1	2	98
				1110	1	2	100

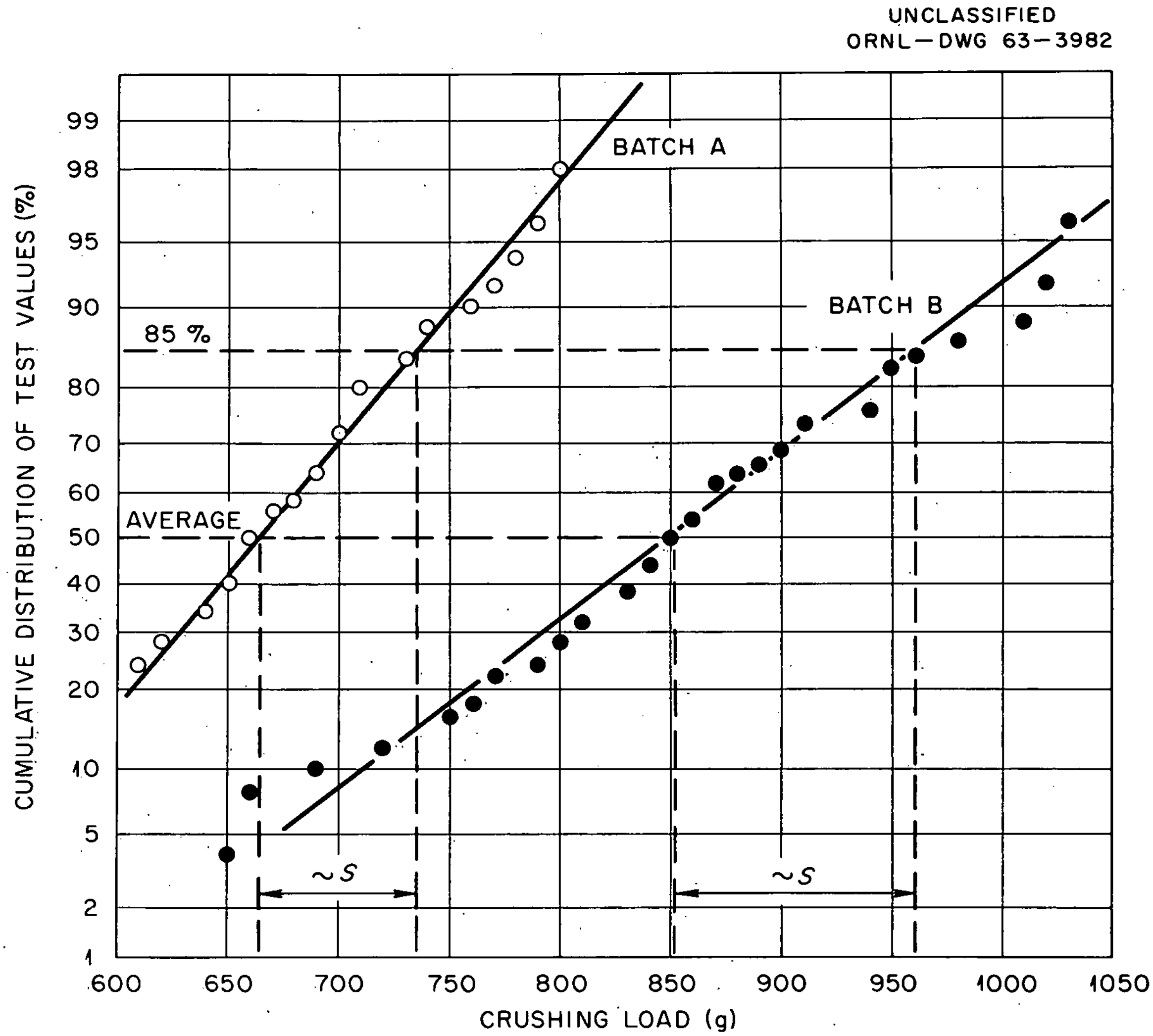

Fig. 5. Crushing Strength Data for Two Batches of Fuel Particles Tested.

In the initial period of six months during which the crushing instrument was in use, 32 batches of fuel particles were tested. A sampling of 50 particles was taken from each batch. The average crushing strength of these samplings varied from 460 to 2560 g; the standard deviation range was 65 to 960 g.

Concluding Remarks

An instrument for crushing-strength determinations of uncoated and pyrolytic-carbon-coated fuel particles was designed and built for the purpose of relating the crushing strength of the particles to their fabricability. At present, this instrument provides the only means for measuring strength of fuel particles. Results of these tests combined with metallographic and other examinations provide the basis for evaluation of various fuel element concepts employing coated particles.

The instrument has been in operation at the Oak Ridge National Laboratory for the past 18 months. The total cost of all the parts was less than $1000. Recently two other "Particle Crush Strength Testers" have become commercially available.[4]

Acknowledgments

The authors wish to express their appreciation to T. J. Henson for conducting most of the crushing-strength determinations and to C. J. McHargue for reviewing this report. Gratitude is also extended to J. L. Cook and E. S. Bomar for supplying the fuel particles.

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[4]American Metal Products Company, Ann Arbor, Michigan, and NUMEC Instruments and Controls Company, Appollo, Pennsylvania.

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