GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA

June 6, 1957

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 1, Project No. A-331
Covering the period from April 15 to June 1, 1957
Contract No. AF33(616)-5191

Dear Sir:

I. Experimental Progress

An outline of the work carried on during this interval is as follows:

Trips were made to the leading aircraft brake and friction materials manufacturers in accordance with Phase 1 of this contract. The manufacturers that were visited and their representatives who were contacted are as follow:

1. Mr. Les Dassie
Auto Specialties
St. Joseph, Michigan

2. Messrs. Bill Du Bois and Bob Herron
Bendix Products Division
Bendix Aviation Corporation
South Bend, Indiana

3. Mr. C. P. Afanador
B. F. Goodrich Company
Wheel and Brake Plant
Troy, Ohio

4. Messrs. F. H. Highley and Jim Wells
Goodyear Aircraft Corporation
Akron, Ohio

All of these producers and their representatives were very cooperative in showing their facilities and discussing their ideas of the desired properties for brake friction materials.

The eighth Annual Airplane Wheel, Brake and Tire Clinic, sponsored by the Goodyear Tire and Rubber Company, was attended. Considerable time was spent with the technical personnel of Goodyear in discussing this project. Of particular interest was the test equipment which should be used in evaluating brake friction materials. The Goodyear Company is using a laboratory type testing instrument which has provided them with test data which correlate very well with actual service data. Complete drawings and recommended modifications for constructing such an instrument with improved characteristics will be provided by Goodyear. Bendix Aviation Corporation has also supplied complete drawings for their laboratory type testing instrument for use in evaluating brake friction materials.

The Wheel, Brake and Tire Clinic provided an excellent review of aircraft brake systems, friction materials and associated problems.

Of considerable interest were the recent attempts to cool aircraft braking systems by air and water. Water held by far the greatest potential in solving the problem. The greatest difficulty came in getting the water uniformly distributed over the braking surfaces without excessive weight from the connecting hoses, water reservoir, etc. It is of interest to note that it was planned to use a porous friction material filled with water in the study of this project. The water would tend to keep the heat, produced as a result of the braking, from raising the temperature of the system beyond the critical point.

II. Program for the Next Interval

From the two laboratory-test-equipment designs, Goodyear's and Bendix's, an instrument will be designed and built for evaluating brake friction materials.

A literature survey will be made for ceramic materials which can be used as friction materials for aircraft brakes.

Respectfully submitted:

J. D. Walton
Project Director

N. E. Poulos
Assistant Research Engineer

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA

July 10, 1957

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 2, Project No. A-331
Covering the Period from June 1 to July 1, 1957
Contract No. AF33 (616)-5191

Dear Sir:

I. EXPERIMENTAL PROGRESS

An outline of the work carried out during this interval is as follows:

DJ✓

Pertinent data were compiled on specific aircraft for the purpose of determining the magnitude of the important parameters in a high-speed high-inertia braking process. The planes investigated were the C-130 and the F-84F. Although the F-84F might not be considered as a harsh test on friction materials, due to the fact that the kinetic energy absorbed per unit area of material is low, it was used primarily to give an idea of the operating values in the braking process. Maximum values were used in all calculations to give fairly reliable results. This facilitated establishing what requirements were needed in the testing device proposed in the contract.

A device similar to those of the Goodyear Aircraft Corporation and Auto Specialties was thought to give the most reliable test for small friction samples. These testers place a dynamic test on the sample rather than a drag test and therefore more closely simulate the braking process. The producers in the aircraft brake industry seem to all agree that it is necessary to test the properties in combination rather than individually.[1]

[1] ASTM Subcommittee III-D, General Notes of Meeting of January 14, 1957.

JUL 10 1957
~~July 2, 1957~~

Commander
Wright Air Development Center

Another trip was made to the Goodyear Aircraft Corporation for the purpose of obtaining operating data on their test device. The Goodyear personnel were very helpful in telling how the apparatus should be set up and the tests run. A few of the shortcomings and some proposed modifications were discussed. The data compiled for the project was of the correct order of magnitude and compared favorably with that of the actual testing device. After conferring with Dr. Vidosic, of the Georgia Tech Mechanical Engineering Department, it was decided that a tester would be designed similar to that of Goodyear's incorporating their suggested modifications and a few of our own.

A literature search was carried out and it was found that little is known about ceramics as brake friction materials. All articles found were of the general nature and little information of value to the project was obtained.

II. PROGRAM FOR THE NEXT INTERVAL

Work on the designing and building of the tester will continue througout the next interval.

Respectfully submitted,

J. D. Walton
Project Director

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA

August 7, 1957

Commander
Wright Air Development Center
Wright Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 3, Project No. A-331 covering the period from July 1 - August 1, 1957.
Contract No. AF33(616) - 5191

Dear Sir:

I. Experimental Progress

An outline of the work carried out during this interval is as follows:

The design of the testing device was continued and integral parts were specified by the Designing Engineers. These parts include drive motor, vee belt power transmission, bearings, shafting, flywheel, generator, tachometer, air ram and instrumentation. These parts are either on hand or have been ordered.

JL

Considerable thought has been given to the design of the test-sample holder. All concerned agree upon a holder consisting of four cylindrical samples having a cross sectional area of 0.25 sq. in. These are spaced at 90° around a circle so as to match a steel mating surface having a 5 1/2" o.d. and a 4 7/8" i.d. It is presently thought that seamless steel tubing will be shrink-fitted around these samples to prevent the samples from shattering.

II. Program for the Next Interval

Construction of the device will continue with a target date of completion set for September 15, 1957. Fabrication techniques for making samples will also be studied.

Respectfully submitted:

J. D. Walton
Project Director

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

N. E. Poulos
Assistant Research Engineer

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA

September 9, 1957

Commander
Wright Air Development Center
Wright Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 4, Project No. A-331 covering the period from August 1 to September 1, 1957
Contract No. AF33(616) - 5191

Dear Sir:

I. Experimental Progress

An outline of the work carried out during this interval is as follows:

The design of the laboratroy testing device was completed. The major components are on hand or have been ordered. No delay in the delivery of components or materials is anticipated. All machine shop drawings are essentially complete and the manufacturing of parts is progressing with some of the sub-assemblies having been completed.

DJ✓

Requests have been sent to four of the leading aircraft brake and friction materials manufacturers for samples of proven aircraft brake friction materials. We expect to fabricate samples to be utilized in some preliminary runs upon the completion of our device. It is hoped that the data obtained from these tests will be comparable to data obtained from an actual brake dynamometer test. A copy of the torque-time curve obtained will be sent to the suppliers of the material for comment.

The ceramic group at Georgia Tech has been engaged in the studying and developing of materials for high temperature use. The results of this work indicate that fused silica and thermitic cermets are two ceramic materials which offer enough promise to be considered as friction materials in the early stages of our test work. Thermitic cermets are mixtures of metal oxides and aluminum which are pressed into the desired shape and ignited at a relatively low temperature. The resulting thermitic reaction produces temperatures in excess of 5000° F, thereby producing cermets which should have a higher melting point than cermets which are produced by conventional techniques. The fused silica does not have as high a melting point as the cermet. Extremely high resistance to thermal shock, the ease with which this material can be molded or pressed into desired shapes and its flexibility to design changes are considerations which make this material desirable for study in a high energy breaking application.

It is intended that fused silica and thermitic cermets be two of the five ceramic materials to be selected for preliminary evaluation as brake friction materials.

II. Program for the Next Interval

All machine shop work involving parts of the testing device will be completed. Assembly of the testing device should be completed to the point where calibrations can be made. Fabrication techniques for making samples will be studied.

Respectfully submitted:

J. D. Walton
Project Director

W. F. Zenoni
Research Engineer

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA

October 7, 1957

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 5, Project No. A-331
Covering the Period from September 1 to October 1, 1957
Contract No. AF33 (616)-5191

Dear Sir:

I. Experimental Progress

An outline of the work carried out during this interval is as follows:

Machine shop and assembly drawings of the laboratory friction material testing device were completed. The Georgia Tech machine shop completed the manufacturing of the parts. Subassemblies are presently being completed, and it is expected that the device will be completely assembled and moved from the shop to the test site by October 15.

DJ

All the purchased components, including instrumentation, are now at hand. One hundred steel friction rings were received from the Goodyear Tire and Rubber Company. These rings will be used as the mating surface for our ceramic friction material. The American Brake Shoe Company has shipped sample pieces of aircraft brake material from which samples will be fabricated for testing on our machine. Test results from this material will be compared with the results obtained from an actual brake dynamometer test.

II. Program for the Next Interval

The testing device will be completely assembled and moved from the shop to the test site. The machine will be tested to insure proper functioning of all components, including instrumentation. Preliminary tests, without the use of the friction parts, will be made in order to enable personnel to become familiar with the operation of the testing device.

Respectfully submitted,

J. D. Walton
Project Director

W. F. Zenoni
Research Engineer

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA

November 5, 1957

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 6, Project No. A-331
Covering the Period from October 1 to November 1, 1957
Contract No. AF33 (616)-5191

Dear Sir:

I. Experimental Program

An outline of the work carried out during this interval is as follows:

The Georgia Tech Machine Shop completed the assembly of the laboratory friction material testing device. Figure 1 shows the device installed at the test site.

DJ ✓

The various components of the machine were checked out separately to insure proper functioning of these parts. Full scale operational tests, with the exception of the friction parts, were made to check out the machine as a whole and to enable personnel to become acquainted with the operation of the unit.

The machine includes a 7-1/2-hp high torque motor which is mounted to the concrete floor, rather than to the frame which supports the machine, to avoid introducing motor vibrations in the test. The motor drives the flywheel shaft by the use of vee belts. An electric clutch is used between the driven vee belt sheave and the flywheel. When the flywheel attains a desired speed, and therefore, a desired kinetic energy, it is disengaged from the motor drive through an electric clutch. The flywheel is made in three segments in order that the kinetic energy may be varied. A variation in RPM can also be used to change the kinetic energy. The end of the flywheel shaft is designed to hold a 17-22-A(S) Timken steel ring that is used as a mating surface for the friction material. The machine was designed to operate up to 3500 RPM and deliver a maximum kinetic energy of 125,000 ft lb.

The friction material to be tested is mounted in the sample holder. Provisions have been made to handle four cylindrical samples 0.625 inches in diameter, spaced 90° apart on a 4-inch diameter circle. The sample holder is connected to an air cylinder which is used to force the friction material against the rotating steel mating surface, causing the braking action. The braking load can be varied from zero to 2000 lb by changing the pressure on the air cylinder.

A load arm fastened to the sample holder transfers the braking torque to a load cell which, in turn, sends a signal to an amplifier. The signal is recorded on a Brush Direct Writing Oscillograph.

Figure 2 shows torque curves obtained with our testing device using a conventional aircraft friction material. A flywheel speed of 2000 RPM and a braking force of 850 lb/sq inch were used in these tests. Curves A and B are the results of samples which were unsupported in the holder. Curves C and D are results of samples enclosed in seamless steel tubing. Since some of our ceramic materials will probably be enclosed, it was felt desirable to compare the torque curves of conventional aircraft material enclosed in a steel jacket with the curves of completely unsupported material.

II. Program for the Next Interval

Fused silica samples will be fabricated and evaluated for use as a ceramic friction material in a braking application. Fabrication techniques utilizing other ceramic materials will be studied.

Approved: Respectfully submitted:

J. D. Walton, Head
Ceramics Branch

W. F. Zenoni
Project Director

Wyatt C. Whitley, Chief
Chemical Sciences Division

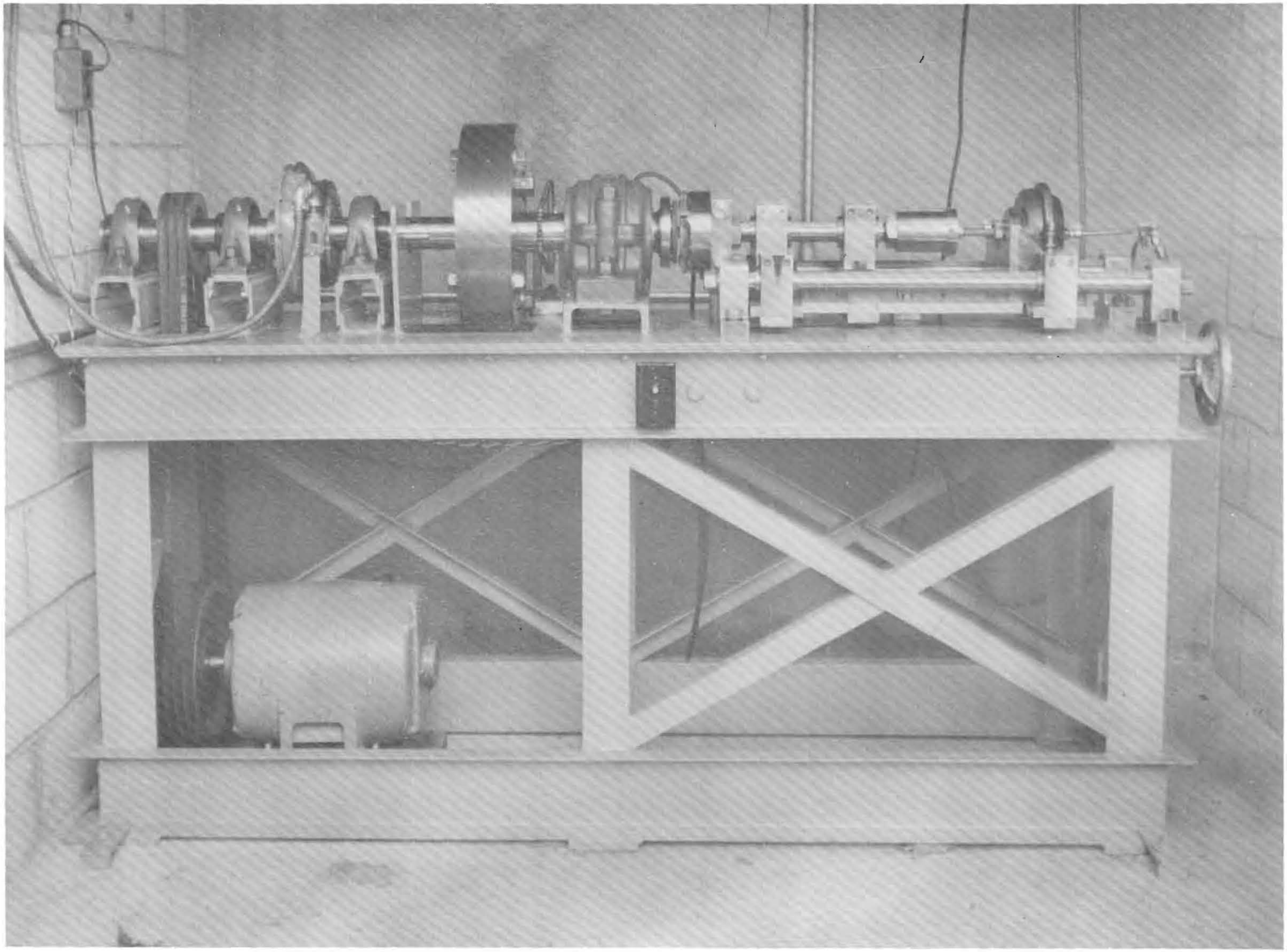

Figure 1. Laboratory Friction Material Testing Device.

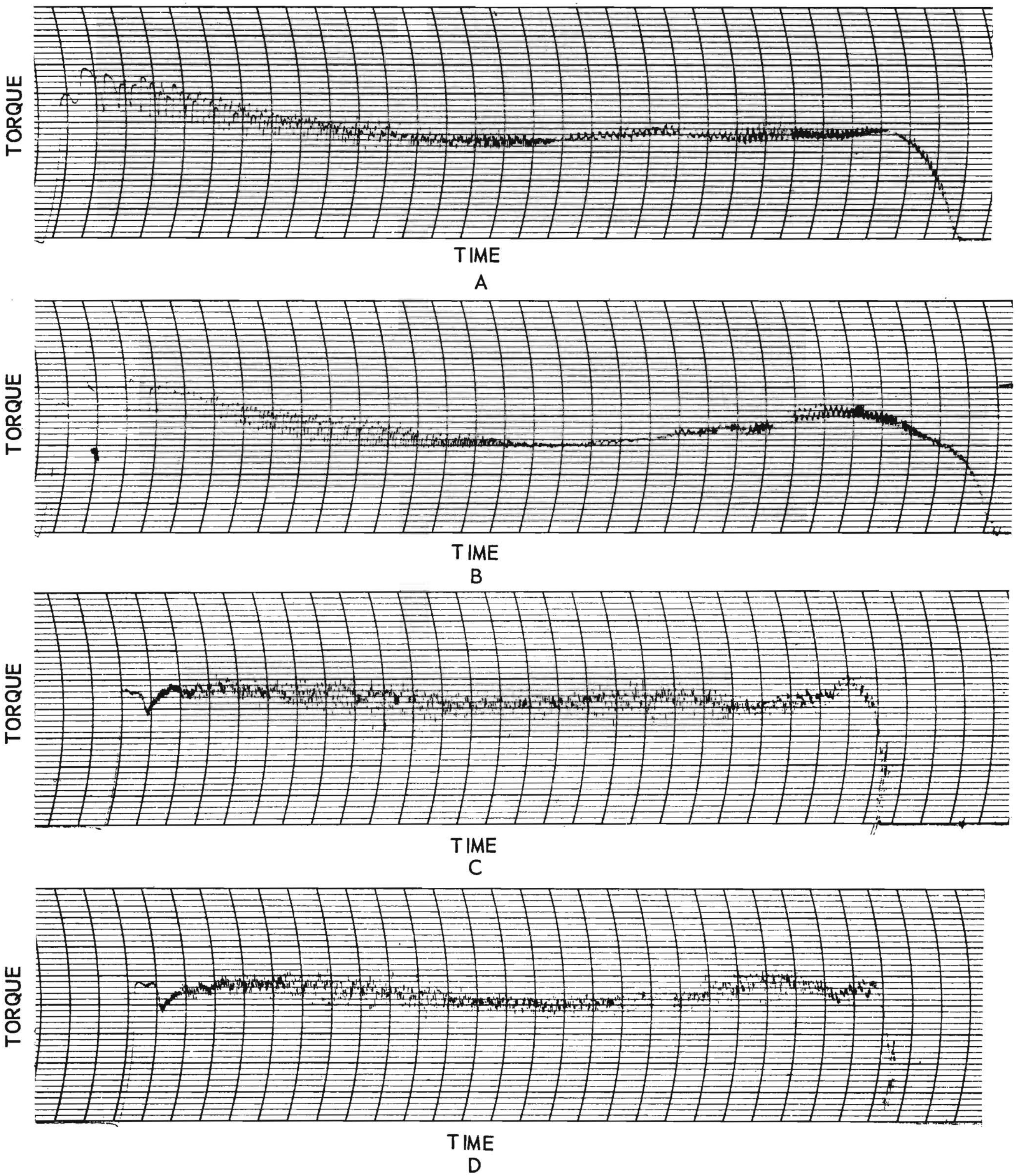

Figure 2.

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA

December 4, 1957

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 7, Project No. A-331
Covering the Period from November 1 to December 1, 1957
Contract No. AF 33 (616)-5191

Dear Sir:

I. Experimental Program

An outline of the work carried out during this interval is as follows:

The effort during this interval was directed toward the fabrication of ceramic base samples to be evaluated as friction parts in a braking application. Fused silica grain and zirconia were used as the main ceramic body in the samples. Samples were fabricated from materials which are presently being used in aircraft brakes.

DJV

Fused silica, -100 mesh grain, was used as the main body of all silica samples. Enough colloidal silica was added to the dry grain to give a mix which could be handled during the pressing operation. The silica sample composition was varied by the addition of purified copper powder and chopped copper turnings in amounts of 20, 40 and 60 per cent by weight. The copper was added in various proportions to indicate possible trends.

Specimens of the various compositions 9/16 inch in diameter and 5/16 inch long were prepared by pressing in a punch and die set at 6000 psi.

All samples were dried at 225° F and then placed in a furnace at 1800° F for one hour. The samples containing copper were fired in lampblack to prevent oxidation. All samples were impregnated with Shell resin X-131 under a vacuum and then pressurized to insure proper penetration of the resin throughout the sample.

Samples were also prepared from a commercially available zirconia base filter powder to which was added 25 per cent by weight of liquid binder. The mixture is allowed to chemically set at room temperature. This combination resulted in a low expansion mass which would withstand temperatures in excess of 2000° F. Composition of the zirconia base samples was varied by the addition of purified copper powder and chopped copper turnings in amounts of 20, 40 and 60 per cent by weight. These samples were made by pouring the zirconia base mix into a copper sleeve 5/8-inch OD, 9/16-inch ID and 5/16-inch long, and allowing the mix to set at room temperature. The material bonds to the copper sleeve resulting in an integral piece which fits the sample holder.

Samples were also fabricated from Haveg Rocketon and Missileon. Sheet stock samples were received from Haveg Industries, Inc., Wilmington, Delaware. Rocketon and Missileon are presently being used in rocket and guided missile work where high temperature resistance is required. They are composed of a high melting silicate with an organic binder. These materials in combination with other additives may possibly lend themselves to use in a high energy braking application.

II. Program for the Next Interval

A test program will be initiated to evaluate the samples that have been fabricated. Ceramic samples will be tested on our laboratory testing device under varying conditions of kinetic energy and breaking force. Torque curves of the ceramic samples will be compared with those obtained from the samples fabricated from friction material which is presently used on aircraft brakes.

Fabrication of ceramic samples will be continued with emphasis being placed on thermitic cermets.

Respectfully submitted,

W. F. Zenoni
Project Director

Approved:

J. D. Walton, Head
Ceramic Branch

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA

January 2, 1958

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 8, Project No. A-331
Covering the Period from December 1, 1957 to January 1, 1958
Contract No. AF 33(616)-5191

Dear Sir:

I. Experimental Program

An outline of the work carried out during this interval is as follows:

Fabrication of samples to be evaluated as friction parts was continued.

Cermet samples, having zirconium disilicide and alumina as principal components, were prepared from a thermitic cermet mix. The mix consisted of 53.8 per cent zirconium silicate, 21.2 per cent powdered aluminum and 25 per cent aluminum oxide. The zirconium silicate and aluminum is considered the thermite mix and the aluminum oxide acts as a throttling agent to give some control over the reaction in addition to aiding as an internal lubricant and binder. Ten per cent by weight of a saturated solution of aluminum hydroxide was thoroughly mixed with the thermite and aluminum oxide to give a mix which could be handled in a pressing operation.

Specimens 3/4 inch in diameter and 3/4 inch long were prepared by pressing in a punch and die set at 10,000 psi. Stearic acid was used as a mold lubricant.

The samples were dried for 2 hours and placed in a laboratory dryer at 110° C overnight. The samples were then contained in a steel box filled with magnesium oxide and placed in a furnace at 1800° F for one hour. The magnesium oxide was used as a shrouding agent to help retain the heat generated by the thermitic reaction. The thermite ignited at a temperature lower than 1800° F and the resulting reaction produced temperatures in excess of 4000° F.

The cermet samples were machined to 5/8-inch diameter and 1/2 inch long by the use of a diamond saw.

Preliminary evaluation tests of ceramic materials for use in a braking application were conducted during the period. Samples evaluated included fused silica, zirconia, thermitic cermet, Haveg Missileon and samples fabricated from two materials presently being used in aircraft brakes. Each sample, with the exception of the cermet, was enclosed in a copper sheath.

A laboratory type inertia dynamometer was used to evaluate the samples. A considerable amount of time and effort was expended in the design and fabrication of this tester. This tester places a dynamic test on the sample rather than a drag test and, therefore, more closely simulates the braking action. It is felt that the braking action of this tester can point out deficiencies in materials being tested for use in a high-energy braking application.

Tests utilizing actual samples were made in order to observe the test equipment under varying conditions of flywheel speed. These initial tests proved to be instructive and pointed out several items which had to be taken into consideration in establishing an operating procedure. It was found that better surface contact between friction surfaces could be obtained, at the start of a test, if the samples were ground to length in the test position and if the mating rings were surface ground to correct for a slight warpage. A 6-inch diameter carborundum wheel was adapted to fit on the end of the flywheel shaft, normally the position for the mating surface. The samples, in testing position, were brought in contact with the carborundum wheel and ground to the same length. This was easily accomplished by hand turning the flywheel. An attempt was made to use four samples spaced 90° apart on a 4-inch diameter circle. Samples exhibited very erratic braking action after only two or three runs at relatively low flywheel speeds. A considerable improvement was noted when two samples diametrically opposed were used. It was also noted that motor vibrations were introduced at certain flywheel speeds. Consequently it was necessary to insure that the drive motor was stopped before the braking action was started. From these early tests, an operating procedure was evolved which was used for all tests.

Briefly, the operating procedure was as follows: Two samples having a combined area of 0.61 square inches were located in the sample holder. Metal spacers were used to compensate for the difference in length between the samples and the cavity in the sample holder. When the samples were in place they were rigidly clamped with approximately 1/8 inch of sample length extending beyond the face of of the sample holder. This portion of the sample was used for testing. The samples were ground to equal length by use of the carborundum wheel. The mating surface was then placed in position. The samples were then brought to within 1/16 inch of the mating surface by the use of a hand wheel. At this point the electric clutch was energized, thereby engaging the flywheel to the drive motor. The motor was turned on and allowed to bring the flywheel to the desired speed, thereby imparting a desired kinetic energy to the steel mating surface. The clutch was disengaged and the motor turned off. Samples were forced against the rotating mating surface by opening an air valve which permitted air to flow to the air cylinder which was connected to the sample holder. An air regulator was used to control the air pressure which produced the braking force. A load arm fastened to the sample holder transferred the braking torque to a pressure cell which transmitted a signal to an amplifier which was connected to a brush recorder. The recorder was turned on just prior to opening the air valve. When the tachometer indicated zero rpm, the run was completed and the friction surfaces were separated by releasing the air pressure.

Each pair of samples was subjected to a series of test runs beginning at 1000 rpm flywheel speed and continuing to 3000 rpm in 500 rpm increments. It was felt that a series of tests of increasing severity would provide more information than a complete destructive test. Each sample was subjected to three stops at each speed if wear permitted. The friction materials were allowed to cool between each stop at which time a visual inspection was performed.

The torque time curves of the silica and zirconia samples were very similar to the curves of the two materials presently being used in aircraft brakes. These curves indicated that the stopping time and coefficient of friction of the ceramic samples were in good agreement with those of the comparative materials. The coefficient of friction was relatively constant from 0 to 1000 rpm and from 0 to 3000 rpm. The ceramic samples did not exhibit any deficiencies which could be attributed to poor thermal shock or lack of compressive strength. The wear resistance of the ceramic materials was not as good as the comparative materials.

A significant decrease in wear resistance was noted after the 2000 rpm stops. Addition of copper in the form of powder and chopped turnings did not appreciably change the torque curves of the silica or zirconia base samples.

The torque time curves of the Haveg Missileon were similar to the curves of the comparative material at 1000 and 1500 rpm stops. At 2000, 2500 and 3000 rpm stops there was a decrease in the coefficient of friction and an increase in stopping time. The wear resistance of the Missileon was very good.

The thermitic cermet samples exhibited a decreasing coefficient of friction with increase of flywheel speed. The torque time curve exhibited a fade characteristic and a peaking torque towards the end of the stop. This is a characteristic of cermets which other brake material manufacturers have observed. The wear resistance of the cermet was very good although a chippage around the periphery of the samples occurred. The chipping could probably be eliminated by enclosing the samples in a metal sheath.

An attempt has been made to report qualitatively the results of the evaluation tests of the ceramic materials. While it is felt that considerably more test work needs to be done to draw definitive conclusions, the results of the tests were thought to be favorable. It is apparent that an intensive composition study of the silica base samples is needed, particularly the high temperature bond strength of the silica grain. Composition studies of the cermet are needed to eliminate the fade and peaking torque which are undesirable in a high-energy braking application.

II. Program for the Next Interval

The test program to evaluate ceramic base friction materials will be continued.

Respectfully submitted,

Approved:

W. F. Zeboni
Project Director

J. D. Walton, Head
Cer~~amic~~ Branch

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA

January 31, 1958

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attention: WCLSM-1

Subject: Letter Report No. 9, Project No. A-331
Covering the Period from January 1 to February 1, 1958
Contract No. AF33 (616)-5191

Dear Sir:

I. Experimental Program

An outline of the work carried out during this interval is as follows:

Brake tests conducted during December on ceramic base friction materials indicated that the wear resistance of fused silica and zirconia samples was not as good as the organic lining presently being used in aircraft brakes. The low wear resistance was attributed to the poor high temperature bond strength of the ceramic grain.

The effort during the month of January was directed towards the improvement of the high temperature bond strength of the fused silica grain. Colloidal silica was used to increase the high temperature bond strength. A composition study of the fused silica grain was also undertaken. This study was restricted to the addition of ceramic materials.

Fused silica, -100 mesh grain, was used as the main body of the samples. Sample composition was varied by the addition of fused alumina, calcined alumina and clay.

Specimens of the various compositions 9/16 inch in diameter and 5/16 inch long were prepared by pressing in a punch and die set at 8000 psi.

All samples were dried at 225° F and then placed in a furnace at 1800° F for one hour. The samples were then soaked with commercially available colloidal silica under a vacuum for one hour. Samples were dried at 225° F and fired at 1800° F for one hour. All samples were subjected to two colloidal silica soaks.

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†Stopping time represents the

B. WEAR

Flywheel Speed (rpm)	Wear† (inches) A	B	C	D	E	F	G
1000	0.001	-	0.001	-	-	0.002	0.001
1500	0.001	-	0.001	-	0.001	0.007	0.001
2000	0.001	-	0.001	0.002	0.001	0.011	0.002
2500	0.003	-	0.001	0.002	0.001	0.010	0.003
3000	0.016	0.004	0.001	0.009	0.004	0.015	0.004

†Wear measurements represent the total wear for three stops at each rpm.

C. TORQUE

Flywheel Speed (rpm)	Torque† (ft lb) A	B	C	D	E	F	G
1000	15.8	16.3	15.8	25.0	27.1	15.8	25.8
1500	26.7	15.0	14.3	35.0	21.3	20.0	22.5
2000	23.3	15.0	13.5	27.5	17.6	17.5	23.3
2500	20.0	16.3	13.5	30.0	21.3	17.5	19.2
3000	20.0	15.0	11.3	25.8	23.1	20.8	17.5

†Torque measurement represents the average of three tests at each rpm.

variation in the friction properties of the copper enclosed and unenclosed Goodyear samples. Unenclosed silica samples appeared to have the same friction properties as those exhibited by the copper enclosed samples. Only one stop was made at each flywheel speed with the unenclosed silica samples because of the bad chippage which occurred after each stop. It appears from the limited number of tests that the effect of the copper sheath is a function of the system being tested.

D. ENERGY ABSORPTION

Flywheel Speed (rpm)	Energy Adsorption (hp/inch^2) A	B	C	D	E	F	G
1000	2.7	3.2	2.9	3.7	4.6	3.8	4.1
1500	5.4	4.5	4.5	6.8	5.7	5.5	5.5
2000	6.8	6.3	5.6	7.5	6.8	6.5	7.4
2500	8.2	7.6	7.3	10.3	9.3	8.1	7.5
3000	9.7	7.9	6.5	10.8	10.7	10.4	8.4

rpm	Energy Absorbed in Stopping† (ft lb)
3000	73,500
2500	51,000
2000	32,700
1500	18,400
1000	8,150

†Energy was absorbed by two samples having a total area of 0.61 sq inch.

II. Program for the Next Interval

The final progress report will be written during the next interval.

Respectfully submitted,

W. F. Zenoni
Project Director

Approved:

J. D. Walton, Head
Ceramic Branch

Frederick Bellinger, Chief
Material Sciences Division

c. 2
A-331

WADC TECHNICAL REPORT 58-118

STUDY AND PRELIMINARY EVALUATION OF CERAMIC BRAKE FRICTION MATERIALS FOR AIRCRAFT

Project A-331

W. F. ZENONI AND J. D. WALTON
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

DJV

APRIL 1958

WRIGHT AIR DEVELOPMENT CENTER

WADC TECHNICAL REPORT 58-118

STUDY AND PRELIMINARY EVALUATION OF CERAMIC BRAKE FRICTION MATERIALS FOR AIRCRAFT

W. F. ZENONI AND J. D. WALTON
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

April 1958

Aircraft Laboratory
Contract No. AF 33(616)-5191
Project No. 1369

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Engineering Experiment Station of the Georgia Institute of Technology under USAF Contract No. AF 33(616)-5191. This contract was initiated under Project No. 1369, Under Carriage Systems Task No. 13505, Brake Friction Materials, and was administered under the direction of the Aircraft Laboratory, Mechanical Branch, WCLSM, Wright Air Development Center, with H. R. Chandler acting as Project Engineer.

This report covers the period of work from 15 April 1957 to 14 April 1958. Principal personnel participating in this work included J. D. Walton, W. F. Zenoni, J. P. Vidosic, R. Trotter and Howard Hamilton.

ABSTRACT

This report summarizes the work completed between 15 April 1957 and 14 April 1958 on the study and preliminary evaluation of ceramic brake friction materials for aircraft.

A laboratory friction material brake tester was designed and fabricated at Georgia Tech. This tester places a dynamic test on the sample rather than a drag test, therefore more closely simulates a braking process.

Samples utilizing zirconia and fused silica as the main ceramic body were fabricated.

An organic resin and commercially available colloidal silica were studied as impregnants for the silica base samples. Silica base sample compositions were varied by the addition of fused alumina, calcined alumina and clay.

Silica samples impregnated with colloidal silica showed considerably better wear resistance than silica samples impregnated with an organic resin.

Silica samples with refractory additions showed friction properties and wear resistance that compared very well with those of organic friction material presently being used in aircraft brakes.

A new type of cermet designated thermitic cermet, developed by the Georgia Tech ceramic group, was included in the test program. Test data were insufficient to permit proper evaluation of this cermet as a brake friction material.

FOR THE COMMANDER:

RANDALL D. KEATOR
Colonel, USAF
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INTRODUCTION

The trend toward high landing speed, high density, supersonic aircraft has out-paced the development of suitable brake friction materials. Friction material failure or malfunction is the most frequent cause of brakes failing to meet specification requirements. Present day friction liners are composed of several materials utilizing an organic resin for a binder. These organic bound friction liners are thought to be operating now at about their upper temperature limit of 1800° F. Current needs exist for friction liners which will withstand service temperatures of 3000° F. It is apparent that new materials must be found to satisfy high energy, high temperature braking requirements for modern aircraft.

Ceramic materials, such as silica and fused alumina, have been used in friction parts for many years. Because of their high abrasive properties, these ceramic materials were used as a means of increasing the coefficient of friction of the friction parts. However, the high heat resistance of ceramic materials in general has not been exploited sufficiently in friction parts that may in service attain temperatures in excess of 2000° F. In considering friction parts which must withstand temperatures of 3000° F and possibly higher, it becomes necessary to completely re-evaluate available materials in the light of present high temperature technology. In this case the materials must be selected on the basis of the physical properties which are most desirable for high temperature friction materials. These properties are:

1. High and Stable Coefficient of Friction
2. High Melting Point
3. Good Thermal Shock Resistance
4. Good Wear Resistance
5. High Compressive Strength

Some work to develop ceramic friction materials has been carried out under USAF sponsorship. In order to further exploit ceramic friction materials, a USAF contract was granted to the Engineering Experiment Station of the Georgia Institute of Technology. Contract No. AF 33(616)-5191 was for the study and preliminary evaluation of ceramic brake friction materials for aircraft.

In order to carry out the requirements of the contract, the following procedure was used.

1. During the initial period of this program, time was devoted to becoming familiar with present and future design requirements for aircraft brakes.

2. A literature survey was made for ceramic materials which have desired properties for use as friction materials for aircraft brakes.

3. A laboratory brake tester was designed and fabricated. Ceramic base samples were fabricated and evaluated on the brake tester.

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EXPERIMENTAL WORK

1. Preliminary Investigation

During the initial period of the program, visits were made to the leading aircraft brake suppliers to obtain a working knowledge of present and future design requirements for aircraft brakes. Visits were also made to various organizations to gain some knowledge of friction material fabrication methods, and the procedures used for testing friction materials in a braking application.

In searching for a suitable testing device with which to evaluate ceramic materials for a braking application, it was learned that the producers in the aircraft brake industry agreed that it was necessary to test material properties in combination rather than individually. As a result of this search, it was decided that a device similar to those of the Goodyear Aircraft Corporation and Auto Specialties was thought to give the most reliable test for small friction samples. These testers place a dynamic test on the sample rather than a drag test and therefore more closely simulate the braking process.

A trip was made to the Goodyear Aircraft Corporation for the purpose of obtaining operating data on their test device. The Goodyear personnel were very helpful in telling how the apparatus should be set up and tests run. The Goodyear organization also agreed to furnish steel friction rings to be used as the mating surface for our ceramic friction material.

A literature search was carried out and it was found that little was published about ceramics as brake friction materials. All articles found were of a general nature and little information of value to the project was obtained. It was felt that a large effort for a literature search was not warranted.

2. Test Equipment and Procedure

a. Equipment

A laboratory type inertia dynamometer, fabricated in the Georgia Tech machine shop, was used to evaluate the friction material samples. The tester was designed to operate up to a flywheel speed of 3500 RPM (brake rubbing velocity 3700 ft/min) and deliver a maximum kinetic energy of 125,000 ft lb. The design incorporates a flywheel made in three segments in order to vary the kinetic energy. (See Appendix A.) A variation in RPM can also be used to vary the kinetic energy. The flexibility in design permits the selection of a wide range of kinetic energies and brake rubbing velocities. An air cylinder is used to control the braking force. The braking force can be varied from zero to 2000 lb by changing the pressure on the air cylinder.

Figure 1 shows the brake tester installed at the test site. This tester includes a 7-1/2-hp high torque motor which drives the flywheel shaft through the use of vee belts, 2. The motor, 1, is mounted to the concrete floor, rather than to the frame which supports the tester, to minimize the effect of motor

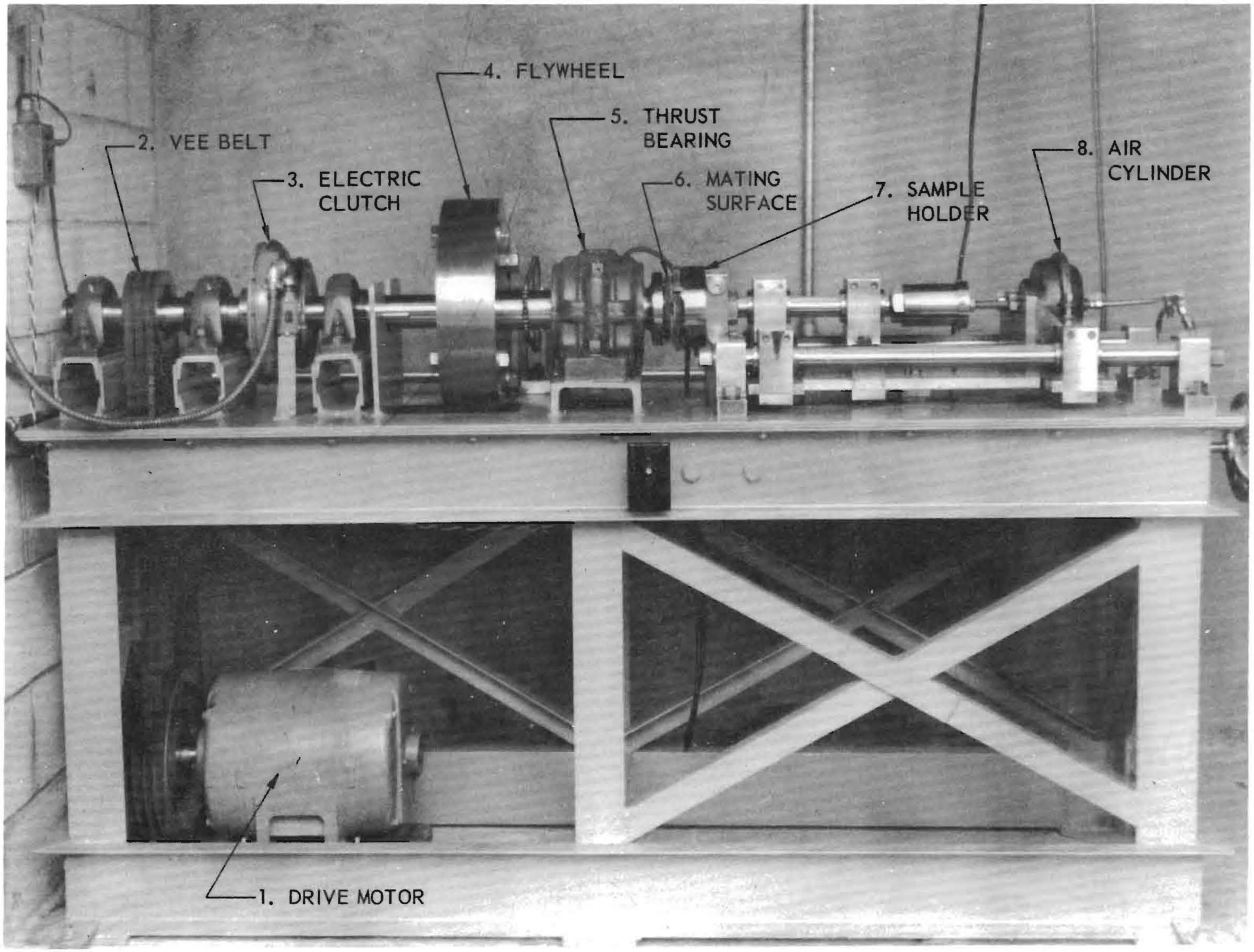

Figure 1. Laboratory Friction Material Tester.

vibrations during a test stop. An electric clutch, 3, is located between the driven vee belt sheave and the flywheel, 4, and serves to engage and disengage the flywheel from the motor. The end of the flywheel shaft is designed to hold a steel ring that is used as a mating surface, 6, for the friction material.

The friction material to be tested is mounted in the sample holder, 7. Provisions were made to handle four cylindrical samples, 5/8 inch in diameter, spaced 9 apart on a 4-inch diameter circle. The sample holder is connected to an air cylinder, 8, which is used to force the friction material, in a horizontal direction, against the rotating steel mating surface causing the braking action.

A vertical load arm fastened to the sample holder transfers the braking torque to a load cell which, in turn, sends a signal to an amplifier. The signal is recorded on a Brush Direct Writing Oscillograph.

A Tachometer generator, fastened to the flywheel shaft by a chain and sprocke is used to indicate the flywheel RPM.

b. Testing Procedure

In order to check out the performance of the test equipment and to become familiar with the type of data obtained from such a test it was decided that an existing aircraft brake friction material would be tested. The material was obtained as an aircraft brake puck and machined into four samples of the required dimensions. Stops were made at various flywheel speeds to observe the type of stop we might consider desirable.

Early in the testing program, it became evident that the use of four samples exhibited a very erratic braking action after only two or three runs at relatively low flywheel speeds. A considerable improvement was noted when two diametrically opposed samples were used.

These tests were followed by a series of tests utilizing ceramic base samples to observe the behavior of ceramic materials in a dynamic brake operation. The samples were badly chipped around the periphery during testing; consequently, it was decided that future samples should be enclosed in a metal sheath prior to testing.

Early tests proved that better surface contact between friction surfaces could be obtained at the start of the test if the samples were ground to equal length while in the test position. A six-inch diameter carborundum wheel was adapted to fit the end of the flywheel shaft, normally the position for the mating surface. The samples, in testing position, were brought in contact with the carborundum wheel and ground to equal length by hand turning the flywheel.

From these early tests an operating procedure was evolved which was used for all future tests. Briefly, the operating procedure was as follows:

(1.) Place two samples in the sample holder diametrically opposed. Clamp samples rigidly in place with approximately 1/8 inch of sample length extending beyond the face of the sample holder.

(2.) Locate carborundum wheel on end of the flywheel shaft and bring samples in contact with the grinding wheel. Grind samples to equal length by hand turning the flywheel.

(3.) Remove carborundum wheel and replace with a 4.625-inch-outside-diameter 17-22-A(s) Timken steel ring (Figure 2) to be used as a mating surface for the friction material.

(4.) Bring samples to within 1/16 inch of the mating surface.

(5.) Set air regulator.

(6.) Energize clutch and turn motor on.

(7.) Allow flywheel to reach desired speed.

(8.) De-energize clutch and turn motor off.

(9.) Turn chart recorder on.

(10.) Open air valve resulting in braking action.

(11.) When tachometer indicates zero RPM, the run is completed and friction surfaces are separated by releasing the air pressure.

Each pair of samples was subjected to a series of test runs beginning at 1000 RPM flywheel speed and continuing to 3000 RPM in 500 RPM increments. It was felt that a series of tests of increasing severity would provide more information than a complete destructive test. Each pair of samples was subjected to three stops at each speed if wear permitted. The friction materials were allowed to cool between each stop at which time a visual inspection was performed and wear data recorded.

3. Ceramic Base Samples

a. Introduction

In considering the properties desirable for a ceramic friction material as outlined in the introduction, it was felt that thermal shock resistance was the principal one which would be considered most difficult to obtain. Fused silica is generally considered to have the optimum thermal shock resistance among ceramic materials. Two other ceramic materials which are frequently used when a lesser degree of thermal shock resistance is required are zirconia and alumina.

Since cermets generally have good thermal shock resistance, it was felt that they should be considered in the program. Personnel at Georgia Tech have been engaged in the development of a new type of cermet, designated as thermitic cermets. Thermitic cermets are mixtures of metal oxides and aluminum which are pressed into the desired shape and ignited at a relatively low

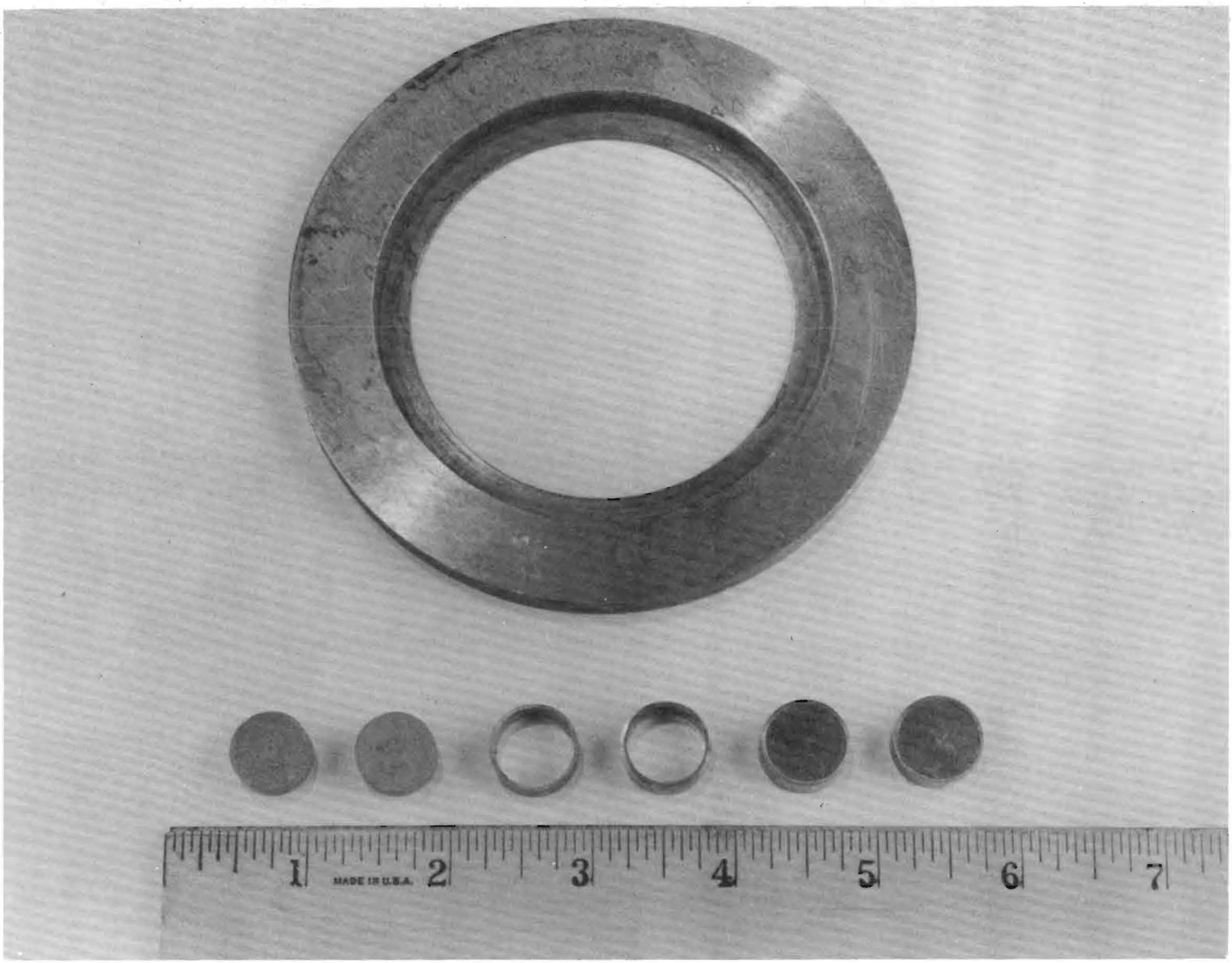

Figure 2. Friction Material Samples and Mating Surface.

temperature. The resulting thermitic reaction produces temperatures in excess of 5000° F, thereby producing cermets which should have a higher melting point than cermets which are produced by conventional techniques. It was felt that the high melting point, better thermal shock than the average ceramic material and expected high wear resistance, made these cermets a promising friction material for a high energy braking application.

b. Preparation and Fabrication

(1) Fused Silica. Fused silica, -100-mesh grain, was used as the main body of all silica samples. Enough colloidal silica was added to the dry grain to give a mix which could be handled during the pressing operation. The silica sample composition was varied by the addition of copper in the form of powder and chopped turnings, calcined alumina, fused alumina and clay.

Specimens of the various composition 9/16 inch in diameter and 5/16 inch long were prepared by pressing in a punch and die set at 8000 psi.

All samples were dried at 225° F in a laboratory dryer and then placed in a furnace at 1800° F for one hour. The samples containing copper were fired in lampblack to prevent oxidation.

An organic resin and commercially available colloidal silica were studied as impregnants to improve the body strength of the fired samples. Samples were impregnated under a vacuum and then pressurized to insure proper penetration throughout the samples. Specimens impregnated with resin were followed by a firing at 400° F for 3 hours. Specimens impregnated with colloidal silica were fired at 1800° F for one hour. Each silica sample was contained in a copper sheath.

(2) Zirconia Base Samples. Samples were prepared from a commercially available zirconia base filler powder to which was added 25 per cent by weight of liquid binder. The mix was poured into a copper sleeve 5/8-inch OD, 9/16-inch ID, and 5/16-inch length, and allowed to set at room temperature. The zirconia sample composition was varied by the addition of copper powder. The material bonded to the copper sleeve, resulting in an integral piece which was ready for testing.

(3) Thermitic Cermet. Cermet samples, having zirconium disilicide and alumina as principal components, were prepared from a thermitic cermet mix. The mix consisted of 53.8 per cent zirconium silicate, 21.2 per cent powdered aluminum and 25 per cent aluminum oxide. The zirconium silicate and aluminum is considered the thermite mix and the aluminum oxide acts as a throttling agent to give some control over the reaction in addition to aiding as an internal lubricant and binder. Ten per cent by weight of a saturated solution of aluminum hydroxide was thoroughly mixed with the thermite and aluminum oxide to give a mix which could be handled in a pressing operation.

Specimens 3/4 inch in diameter and 3/4 inch long were prepared by pressing in a punch and die set at 10,000 psi. Stearic acid was used as a mold lubricant.

The samples were dried for 2 hours at room temperature and placed in a laboratory dryer at 110° C overnight. The samples were then contained in a steel box filled with magnesium oxide and placed in a furnace at 1800° F for one hour. The magnesium oxide was used as a shrouding agent to help retain the heat generated by the thermitic reaction.

The cermet samples were machined to 5/8-inch diameter and 1/2-inch length by the use of a diamond saw.

(4) Rocketon and Missileon. Samples were fabricated from Rocketon and Missileon sheet stock furnished by the Haveg Industries, Inc., Wilmington, Delaware. These materials are presently being used in rocket and guided missile work where high temperature resistance is required. They are composed of a high melting silicate with an organic binder.

4. Results of Laboratory Dynamometer Tests

a. Preliminary Dynamometer Test Data

A series of preliminary brake tests were conducted to develop a testing procedure and to observe the behavior of ceramic bodies in a dynamic braking application. Torque-time curves were obtained for an organic liner presently being used in aircraft brakes in order to have a basis for comparing the test results of the ceramic materials. Typical curves are shown in Appendix B.

The results of these tests are reported in Table I.

The torque-time curves of the silica and zirconia samples were very similar to the curves of the organic liner presently being used in aircraft brakes. These curves indicated that the stopping time and coefficient of friction of the ceramic samples were in good agreement with those of the comparative material. The ceramic samples did not exhibit any deficiencies which could be attributed to poor thermal shock or lack of compressive strength. The wear resistance of the ceramic materials was not as good as the comparative material. A significant decrease in wear reisitance was noted after the 2000 RPM stop.

Addition of copper in the form of powder and chopped turnings did not appreciably change the torque curves or wear resistance of the silica or zirconia base samples.

The torque-time curves of the Haveg Missileon were similar to the curves of the comparative material at 1000 and 1500 RPM stop. At higher RPM stops there was a decrease in the coefficient of friction and an increase in stopping time. The wear resistance of the Missileon was good.

The thermitic cermet samples exhibited a decreasing coefficient of friction with increase of flywheel speed. The torque-time curve exhibited a fade

TABLE I

PRELIMINARY DYNAMOMETER TEST DATA

Composition	Flywheel Speed (RPM)	Average Torque†	Maximum Torque†	Stop Time (Seconds)	Energy Absorbed in Stopping (Hp/In^2)	Remarks
Goodyear organic with copper sleeve	1500	11.2	13	8.6	6.2	Two stops at 3000 RPM
	2000	8.5	10.6	15	6.4	
	2500	8	10.6	18.6	8.2	
	3000	8.5	13	21	10.4	
Goodyear organic	1500	11.7	13.3	8.8	6.0	
	2000	10	13	13.7	7.1	
	3000	8.8	14	19.4	11.3	
Fused silica, resin impregnated	1500	11	13	8.9	5.9	Two stops at 2500 RPM wear resistance poor
	2000	11.3	13	11.7	8.9	
	2500	12	14	16.2	9.4	
80% Fused silica, 20% copper powder, resin impregnated	1500	11	12.5	9.7	5.5	One stop at 3000 RPM wear resistance poor
	2000	10.8	13	12.1	8.0	
	2500	9.8	11.3	16.2	9.4	
	3000	8.5	10	22.2	9.9	
60% Fused silica, 40% copper powder, resin impregnated	1500	11.5	12.5	8.6	6.2	Two stops at 2000 RPM one stop at 3000 RPM wear resistance poor
	2000	11.3	13	11.7	8.3	
	3000	8.5	10	20.6	10.6	
40% Fused silica, 60% copper powder, resin impregnated	1500	12.3	13.3	7.7	6.8	Two stops at 2000 RPM two stops at 2500 RPM one stop at 3000 RPM wear resistance poor
	2000	11	13.3	10.6	9.2	
	2500	11.5	12.5	14.8	10.2	
	3000	12	14	19.8	11.1	

Note: A braking force of 250 lb was used for each test.

(Continued)

TABLE I (Continued)

Composition	Flywheel Speed (RPM)	Average Torque†	Maximum Torque†	Stop Time (Seconds)	Energy Absorbed in Stopping (Hp/In.^{2})	Remarks
80% Fused silica,	1500	11.2	13	9.2	5.7	Two stops at 2000 RPM
20% copper	2000	11.7	14	12.1	8.0	two stops at 2500 RPM
turnings, resin	2500	11.5	14	15.3	9.9	one stop at 3000 RPM
impregnated	3000	10	11	20.2	10.8	wear resistance poor
60% Fused silica,	1500	12.5	14.5	8.2	6.5	One stop at 3000 RPM
40% copper	2000	12.1	14.2	11.6	8.4	wear resistance poor
turnings, resin	2500	11.1	12.1	15.4	9.8	
impregnated	3000	10	11.5	19.2	11.4	
40% Fused silica,	1500	12.3	13.8	8.5	6.2	Two stops at 2500 RPM
60% copper	2000	11.3	13.5	11.1	8.8	wear resistance poor
turnings, resin	2500	10.7	12.5	14.5	10.4	
impregnated	3000	10	12	18.2	12.0	
Zirconia	1500	13	14.7	8.5	6.2	Two stops at 2000 RPM
	2000	11	13.5	12.6	7.7	one stop at 2500 RPM
	2500	10	17	16.2	9.4	wear resistance poor
80% Zirconia,	1500	12.1	15	8.3	6.3	One stop at 2000 RPM
20% copper	2000	11	13	12	8.1	one stop at 2500 RPM
powder	2500	9	13	16.2	9.4	wear resistance poor
60% Zirconia,	1500	14.4	15.8	6.9	7.7	One stop at 2000 RPM
40% copper	2000	11.5	12.5	12.0	8.1	Wear resistance poor
powder						

Note: A braking force of 250 lb was used for each test.

(Continued)

TABLE I (Concluded)

Composition	Flywheel Speed (RPM)	Average Torque†	Maximum Torque†	Stop Time (Seconds)	Energy Absorbed in Stopping (Hp/In.^{2})	Remarks
Cermet	1500	10	14	12.1	4.4	Samples chipped around periphery; two stops at 2500 RPM wear resistance good
	2000	7	15	18.6	5.2	
	2500	5	14.5	29.7	5.1	
Rocketon with copper sleeve	1500	8.1	9.8	12	4.4	One stop at 3000 RPM
	2000	6.8	9.1	19.1	5.1	
	2500	6.8	8.3	23.3	6.5	
	3000	8	12	24.6	8.9	
Missileon with copper sleeve	1500	8.3	9.7	11.7	4.5	Two stops at 2000 RPM two stops at 2500 RPM
	2000	7	8.3	17.9	5.4	
	2500	5.8	7.3	25.8	5.9	
	3000	3.5	7	44.4	4.9	

†Torque Measurements are in chart divisions.

Note: A braking force of 250 lb was used for each test.

characteristic of cermets which other brake material manufacturers have observed. The wear resistance of the cermet was very good, although a chippage around the periphery of the samples occurred. The chipping could probably be eliminated by enclosing the samples in a metal sheath.

b. Further Dynamometer Test Data

From the results obtained in the preliminary tests it was decided that remaining time available should be used to study further the silica base composition.

Silica base samples utilizing refractory additions for composition variation were fabricated. Colloidal silica was used as an impregnant in these samples to improve high temperature strength.

Tests results of these samples are reported in Table II.

A considerable improvement was noted in the wear resistance of the colloidal silica impregnated samples over those impregnated with the organic resin.

The addition of refractory materials to the silica base sample resulted in an increase in torque (coefficient of friction), and a reduction of stopping time.

TABLE II

FURTHER DYNAMOMETER TEST DATA

Composition	Flywheel Speed (RPM)	Average Torque (Ft Lb)	Maximum Torque (Ft Lb)	Stop Time (Seconds)	Average Wear (Inches)	Energy Absorbed in Stopping (Hp/In.^{2})	Remarks
Goodyear organic liner	1500	27	29.2	10.1	.0003	5.2	
	2000	23	29.5	14.3	.0003	6.8	
	2500	20	26.3	18.8	.001	8.1	
	3000	20	26.7	22.7	.005	9.7	
Fused silica, colloidal silica impregnated	1500	15	29	12.4	-----	4.3	Maximum torque was observed as a peaking at the end of the stop
	2000	15	30	15.4	-----	6.3	
	2500	16.2	32.7	20.2	-----	7.5	
	3000	15	32.7	27.9	.001	7.8	
90% Fused silica, 10% fused alumina, colloidal silica impregnated	1500	14.3	27	12.1	.0003	4.4	Maximum torque was observed as a peaking at the end of the stop
	2000	13.5	27	17.3	.0003	5.6	
	2500	17.3	30	20.9	.0003	7.3	
80% Fused silica, 20% fused alumina, colloidal silica impregnated	1500	35	50.3	8.1	-----	6.5	Maximum torque was observed as a peaking at the end of the stop
	2000	27.5	49.2	12.8	.0007	7.6	
	2500	30	39.2	14.7	.0007	10.3	
	3000	25.8	37.5	20.3	.003	10.8	
70% Fused silica, 30% fused alumina, colloidal silica impregnated	1500	21.3	33	9.6	.0003	5.5	Maximum torque was observed as a peaking at the end of the stop
	2000	17.6	34.5	14.3	.0003	6.8	
	2500	21.2	32.3	16.3	.0003	9.3	
	3000	23.1	30.4	20.5	.002	10.7	

Note: A braking force of 250 lb was used for each test.

(Continued)

TABLE II (Continued)

Composition	Flywheel Speed (RPM)	Average Torque (Ft Lb)	Maximum Torque (Ft Lb)	Stop Time (Seconds)	Average Wear (Inches)	Energy Absorbed in Stopping (Hp/In.^{2})	Remarks
80% Fused silica, 20% clay, colloidal silica impregnated	1500	22.5	34.2	10	.0003	5.3	Maximum torque was observed as a peaking at the end of the stop
	2000	23.3	37.5	13.1	.0006	7.4	
	2500	18.3	33.3	20.3	.001	7.5	
	3000	17.5	29.2	25.9	.001	8.5	
80% Fused silica, 20% clacined alumina, colloidal silica impregnated	1500	16.3	27	10.1	.002	5.2	Maximum torque was observed as a peaking at the end of the stop
	2000	17.5	25	14.9	.003	6.5	
	2500	17.5	22.5	18.9	.003	8.0	
	3000	20.8	32	21	.005	10.4	

Note: A braking force of 250 lb was used for each test.

CONCLUSIONS

1. A laboratory brake tester was designed and fabricated. A great deal of effort was expended in the direction of obtaining a tester which could point out deficiencies in materials being tested for use in a high energy braking application.

2. A testing procedure was established for the evaluation of ceramic friction materials.

3. Fused silica base samples impregnated with an organic resin exhibited poor wear resistance. Copper additions in the form of powder and chopped turnings did not appreciably change the wear resistance.

Fused silica base samples impregnated with commercially available colloidal silica showed considerably better wear resistance than those impregnated with an organic resin. Refractory additions to these samples resulted in an increase of friction and a decrease in stopping time. The wear resistance and friction properties of these samples compared very well with those of the organic friction material presently being used in aircraft brakes.

Ease of fabrication, low specific gravity (2.2) and low material cost should all contribute to making fused silica base materials very desirable from a weight and economy standpoint.

4. Zirconia base samples exhibited poor wear resistance. This was attributed to poor bond strength of the ceramic grain.

5. Because of the limited time available, only one thermitic cermet composition was tried. This cermet exhibited excellent wear resistance but exhibited a fade characteristic in stopping. Further composition studies are needed to properly evaluate thermitic cermets as friction materials.

RECOMMENDATIONS

Because of the encouraging data obtained for the fused silica base samples, it is recommended that an intensive program be carried out to evaluate this material as a basic aircraft brake friction material.

If these laboratory evaluation tests confirm the anticipated suitability of this basic material for high energy brake applications, full scale brake dynamometer tests should be initiated as a final phase of this study.

Studies should also be initiated to determine the factors which affect the desired properties which might be obtained using the thermitic cermet process as a means of producing high wear resistant brake friction material.

APPENDIX A

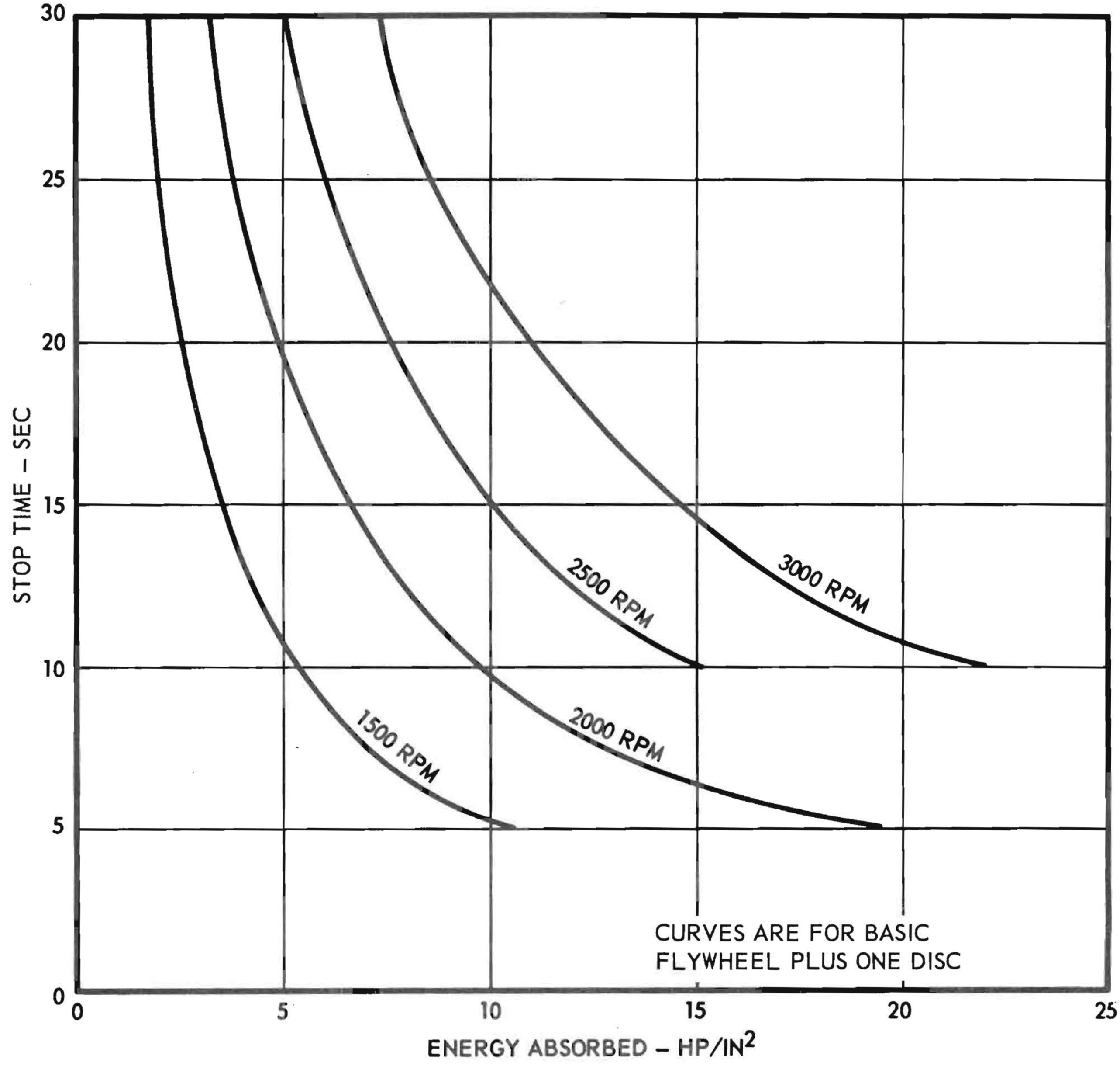

Figure 3. Energy Absorbed in Stopping 0.61 in.^{2} of Friction Lining Material as a Function of Flywheel Speed and Stop Time.

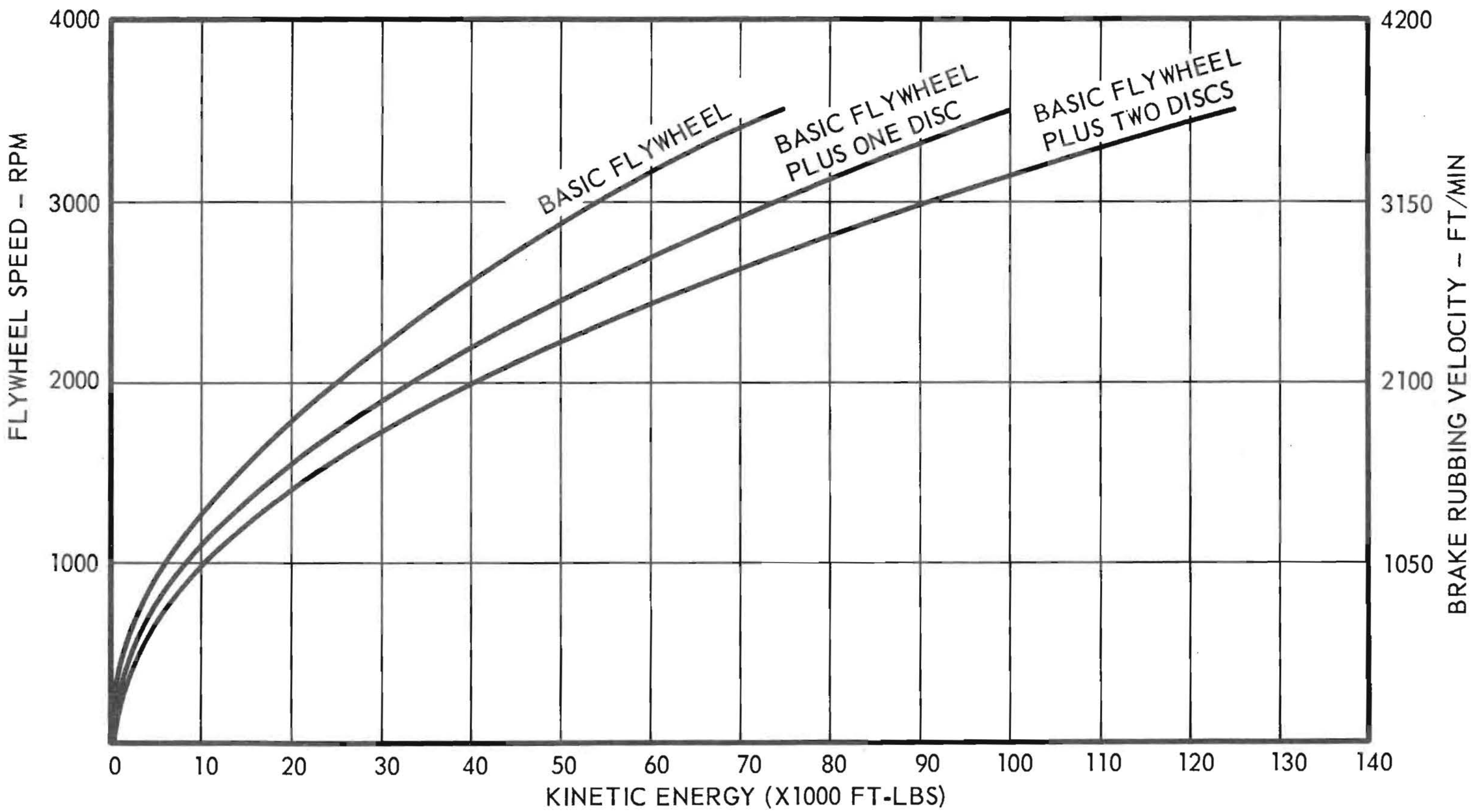

Figure 4. Kinetic Energy as a Function of Flywheel Speed and Flywheel Size.

APPENDIX B

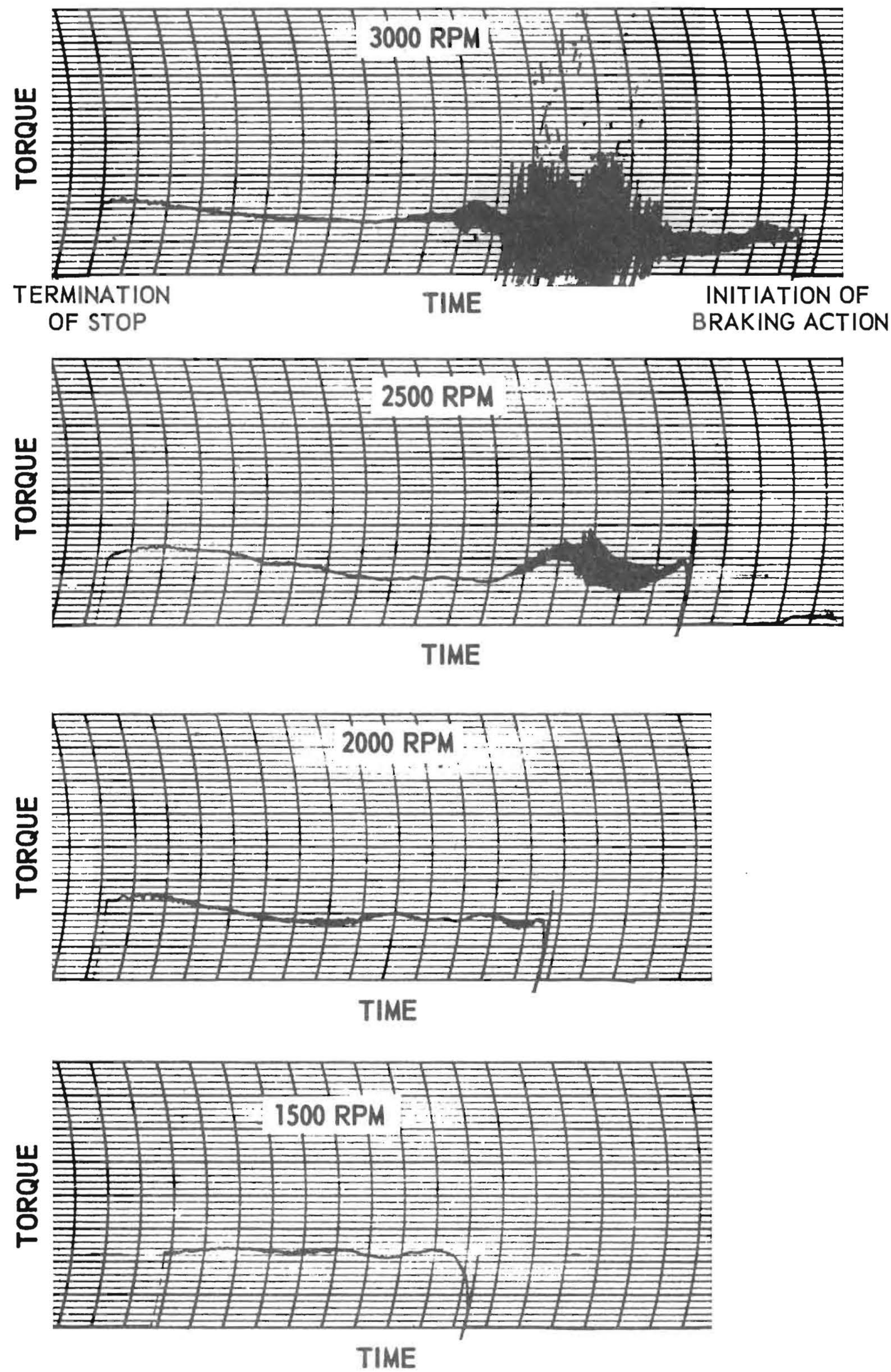

Figure 5. Goodyear Organic Liner Torque-Time Curves.

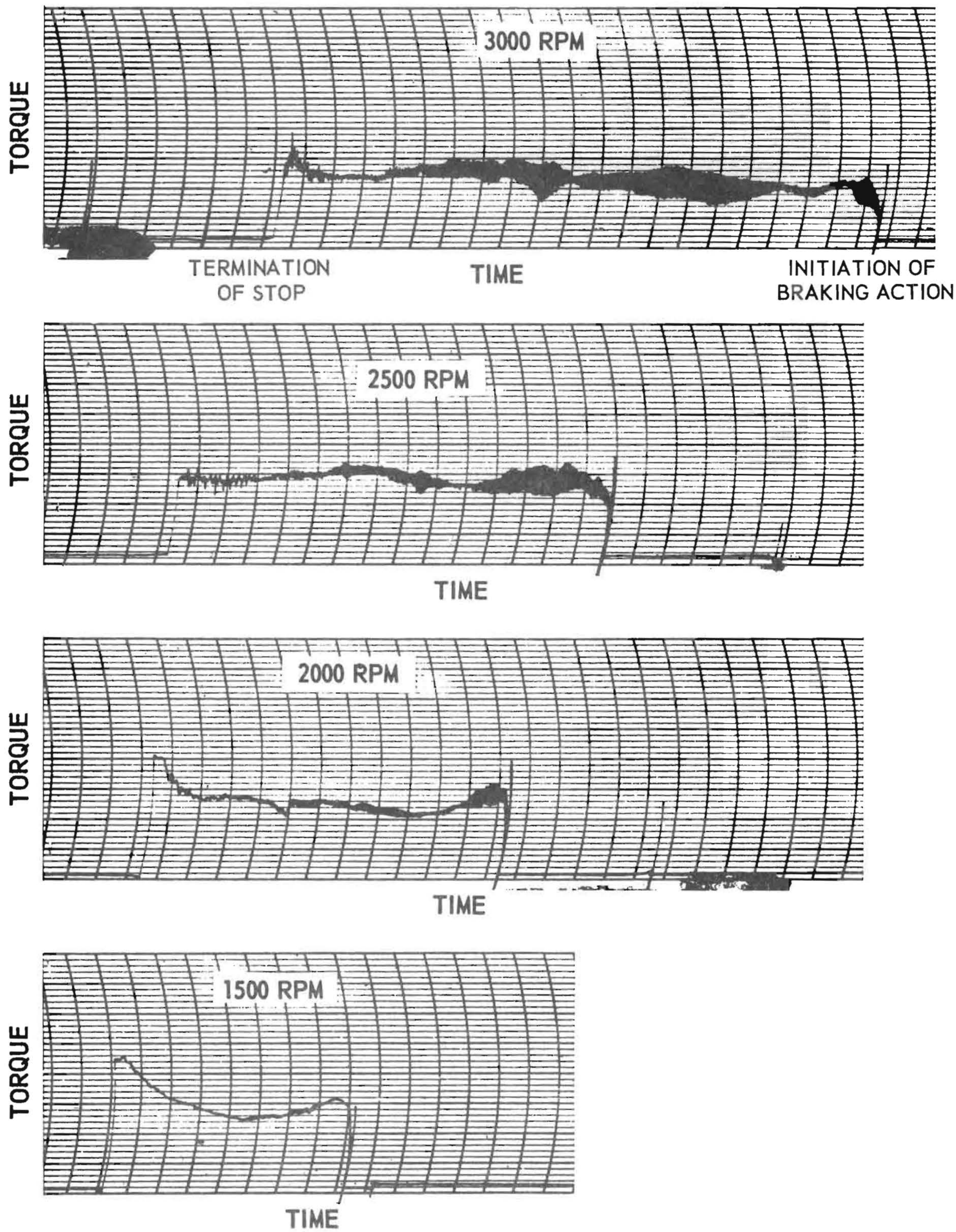

Figure 6. Eighty Per Cent Fused Silica - Twenty Per Cent Fused Alumina Torque-Time Curves.

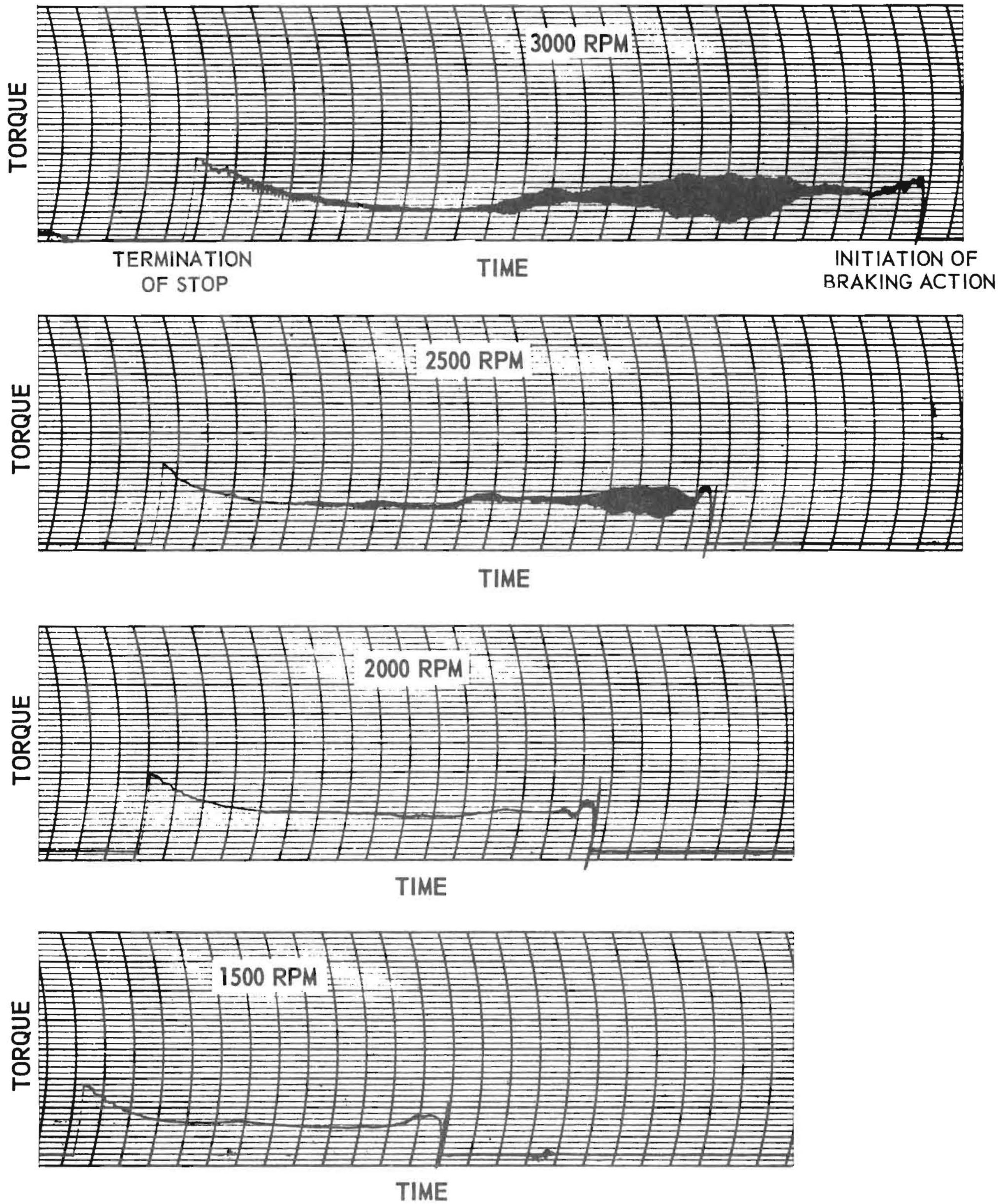

Figure 7. Fused Silica, Colloidal Silica Impregnated, Torque-Time Curves.

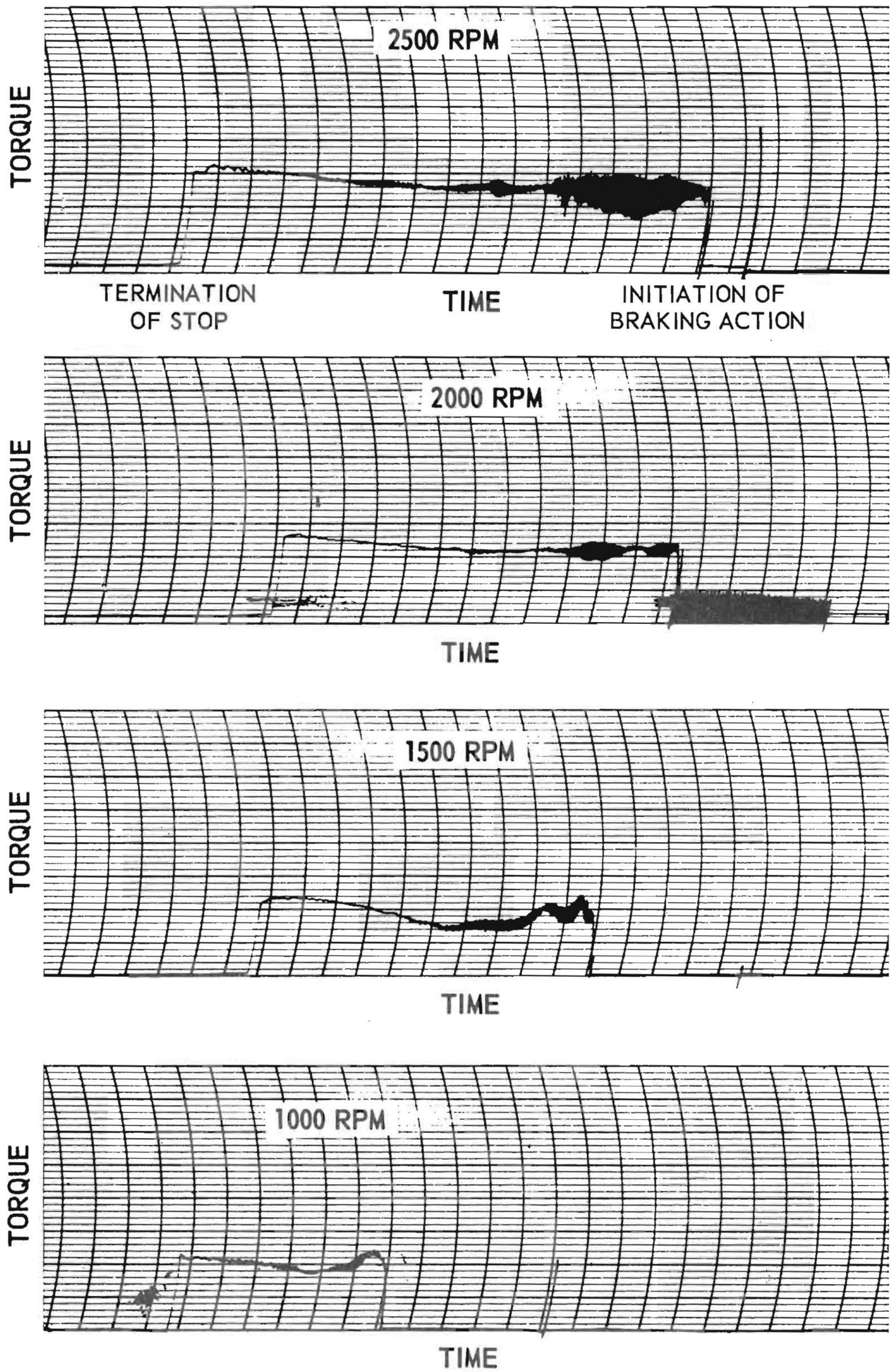

Figure 8. Fused Silica, Resin Impregnated, Torque-Time Curves.

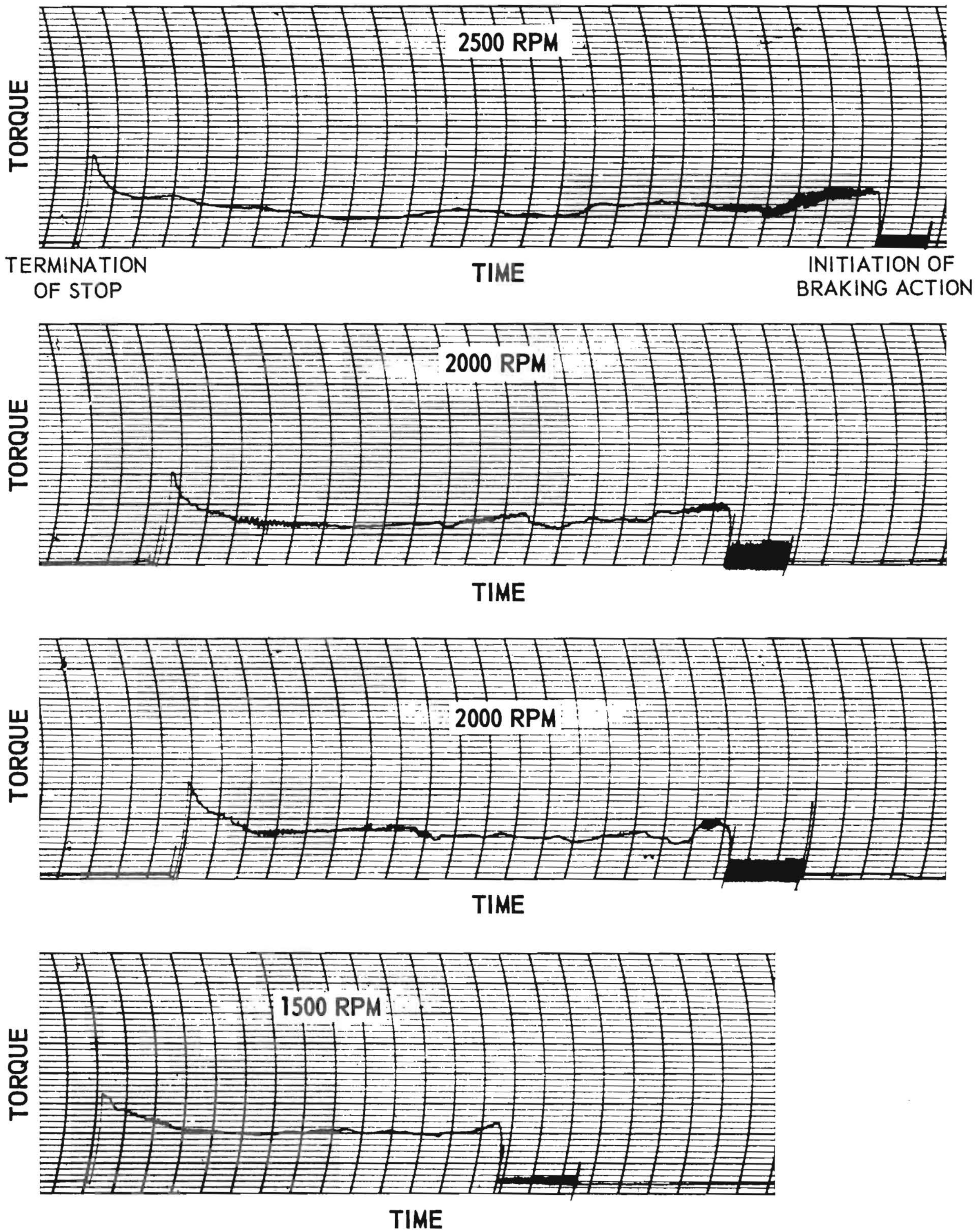

Figure 9. Thermitic Cermet Torque-Time Curves.