ITEM No. 5

FILE No. XXV–9

DEVELOPMENT OF CERAMIC MATERIALS FOR USE IN TURBINE ENGINES

COMBINED INTELLIGENCE OBJECTIVES SUB COMMITTEE

DEVELOPMENT OF CERAMIC MATERIALS FOR USE IN GAS TURBINE ENGINES

Reported By
F/L G.H. DE WITT, R.C.A.F.

CIOS Target Number 5/223
Jet Propulsion

COMBINED INTELLIGENCE OBJECTIVES SUB-COMMITTEE
G-2 Division, SHAEF (Rear) APO 413

TABLE OF CONTENTS

Illustrations:

Development of Ceramic Materials
for use in Gas Turbine Engines
at
I.F.A.

By F/Lt G.H. de Witt, M.A.P.

I - Introduction

Information contained in this report was accumulated by the undersigned from an investigation carried out at the above location and from interviews with the following German Engineers:

Dr. E. Schmidt	-	Director of Engine Research
Dr. Dirksen	-	Director of Materials
Mr. Solngen	-	Assistant to Dr. Schmidt and in charge of the development of ceramic materials for gas turbine blades.

German reports referred to in this paper are now being held by the U.S.S.T.A.F. administrative staff at IFA and copies may be obtained upon request from ADI(K), Document Section.

Ceramic coated metallic blades were not considered for development at the Hermann Goring Institute, IFA, as previous trial with steam turbines had proved unsuccessful, therefore the contents of this article deal chiefly with ceramic materials for use in gas turbine blading.

II - History

The possibility of using ceramic materials in gas turbine engines was first investigated at IFA about [illegible]. The materials tested in this and the following three years were not found to be satisfactory and consequently very little effort was made towards their development. Initial experiments were on ceramic jets or nozzles in which it was found that a nozzle constructed from several segments, rather than one solid ring, could withstand higher temperatures.

References:

(1) "Zusammenstellung der bisherigen Versuchsergebnisse and 8 Dussen".
Date May 7, 194[illegible]; No. F 46 - [illegible].
(2) "Festigkeit Keramischer Werkstoffe und Wärmebelastbarkeit Keramischer Bauteile", by Dr. Dirksen, No. F 22/45.

In the summer of 1944 the German Air Ministry, realizing their acute shortage of nickel and chromium (both of which are required for the manufacture of high temperature steels), ordered LFA to commence an immediate investigation into the possibility of utilizing ceramic materials in place of the aforementioned metals. Companies manufacturing ceramic parts were contacted for materials, and test samples of various sizes and shapes were forwarded. These specimens were from materials already in use for electrical and household purposes and were not found satisfactory for blading assemblies in gas turbines. Firms such as, Stemag (Berlin), Hescho (Hermsdorf), Degussa (Frankfurt), Koppers (Dusseldorf), Porzellan-Manufaktur (Berlin), and Osram (Berlin) were requested to carry out research on the possibilities of developing ceramic materials of sufficient strength to withstand the high stresses and temperatures required for use in gas turbines. Several combinations were tried with a fair degree of success but the majority were limited to 700°C. Materials, such as Dug, which appeared to be the most promising, were not suggested until only a few months before the German country was occupied and therefore they did not have sufficient time to prove their qualities.

III - Materials and Manufacture

The following table lists the most important ceramic materials, their composition, and place of manufacture.

Group	Name	Composition	Manufactured at
1	Steatit Kevafar Sipa 14 Sipa H Frequenta	$Si\ O_2\ H_2O\ Mg\ O$	Stemag, Berlin
2	Sicalit Hartporzellan Calit Ardostan Pyrodur	Calit + 30% SiC -------- -------- -------- --------	Hescho, Hermsdorf
3	Sintertonerde Sinterbery II	Al_2O_3 Be O	Degussa, Frankfurt
4	Sillimanit 10 A Tonerde T. E.	$Al_2O_3\ H_2O\ Si\ O_2$ --------	Koppers, Dusseldorf
5	K-Masse Prokorund Hartporzellan SiC-Masse	$Al_2O_3\ Si\ O_2$	Porzellan - Manufaktur Berlin

Group	Name	Composition	Manufactured at
6	Dug	50% Al_2O_3 + 50% Fe	Osram, Berlin
	------	30% Al_2O_3 + 70% Fe	Siemens-Halske, Berlin
	------	70% Al_2O_3 + 30% Fe	Branch of LFA, Riva, Italy

Materials for the ceramics listed in Group I came from India and could not be obtained after their pre-war supply had been exhausted in 1941. It was found that tensile and bending stresses could be increased by a combination of Al_2O_3 and $Si\ O_2$ (see Group 5) but these failed due to a sudden temperature changes. A combination of Fe and Al_2O_3 produced the best results but the addition of Fe increased the coeff. of expansion of the material.

Four methods of obtaining blade shapes are as follows:

(1) Pressing: The powders were placed in a form and subjected to high pressure at both ends. This procedure was not successful for blades whose ratio of length to width was greater than two since a uniform pressure could not be obtained throughout its length.

(2) Vibrating: To overcome the difficulty encountered in pressing the powders, a vibration method was developed. This was found unsatis-factory as the powder would not bond sufficiently to make a strong ceramic.

(3) Extruding through a Nozzle: Some ceramic materials were successfully extruded through a nozzle having the desired blade profile, but the chief difficulty in this method was to prevent the material from warping while drying at 100°C.

(4) Moulding: In this method of blade manufacture, water is mixed with the ceramic materials and poured into a gypsum mould. The mould is then placed in an oven and heated for several hours at 100 - 300°C until all the water is removed through the porous gypsum mould. The mould is then separated and the blade hand filed to its correct shape before final baking.

Length of time required for the final heating varies and also the temperature (1200°C - 1900°C) depending on the materials used.

In order to prevent a large temperature gradient throughout the blades thickness hollow ceramic blades were developed. According to Dr.Schmidt these blades were not used and test reports could not be found.

IV - Tests

For an Institute responsible for the development of ceramic materials very few strength test reports could be located. Those of primary importance are:

(1) "Versuche zur Bestimmung der Warmefestigkeit von Keramik", date August 15, 1944: No.66701/1.

(2) "Flichkraft-Zugversuch an Keramik-Schaufelproben" by Mr.Kalisch, date September 1943; No.2092.

The first report gives photographs and details of the measuring apparatus and also curves for Sillimanit 9i, Sillimanit 10 A, and Frequenta in tension, compression, and bending. Curves for these materials are reproduced in Fig. I, II, and III respectively. It may be seen from the graphs that those materials (containing Al_2O_3 and Mg O) may be used only if the temperatures remain below 700°C. Above this point the physical properties of the materials deteriorate rapidly.

The most promising ceramics of the list previously quoted are Dug, Si C, and Sintertonerde but, unfortunately, no test results are available. The German Engineers interviewed claimed that they did not have time to prove their characteristics but felt that Dug could be used for stationary blades at temperatures as high as 1000°C.

From the results of these tests it would appear that the development of ceramic materials at LFA had progressed to the point where blades could be manufactured and used in gas turbines at temperatures not exceeding 700oC. Further, because of their low tensile stress limitations they could not be used for blading in an orthodox rotor assembly.

V - Schemes.

T_1 (See Fig. IV) - As the need for the discovery of a material and design to replace high temperature steels increased an experimental four stage axial turbine, having the blades and bases of both the rotor and stator of solid ceramic material, was proposed. To prevent failure of the material at high tensile loads it was found necessary to mount the rotor blades internally on an external drum. In this design the forces acting in the turbine blades produced only a bending and compressive stress. In the rotor the blades were held in place by lugs on steel rings so arranged to provide a small clearance between blade root segments to allow for expansion of the materials at high temperatures. The whole assembly was held together by flanges on the steel drum. Steps were formed in the base of the stator blades to provide a location for steel bands which acted as separators and supports. Cooling air was provided at the base of both the rotor and stator blades.

A ceramic material manufactured by Stemag, Berlin, and known as Sipa H was chosen for use in this experimental turbine. As Stemag was operating under extreme wartime difficulties there was considerable delay in procuring the blades and they were not delivered until the latter part of 1944.

In the interim, Dr. Schmidt had developed and run a single stage water cooled turbine using water cooled guide vanes and operating at 12,000 R.P.M. and 1200° C. With reference to schemes T_2 and T_3, neither of which used ceramic materials, see G/C Constant's report on gas turbine engine research at LFA.

As Dr. Schmidt's water cooled turbine had operated satisfactorily it was decided to cease work on T_1, which was only partially constructed, and concentrate their efforts to the development of ceramic materials for use in stationary guide vanes. Various materials and blade profiles were tested in a hot gas stream but all the materials available failed at temperatures about 800°C (materials containing Fe and Al_2O_3 were not available). The personnel interviewed believed that higher temperatures could be attained with proper root fixtures and cooling as improved ceramic materials were in sight.

VI - Mechanical Arrangements

Due to the relatively high coefficient of expansion of ceramic materials it was generally agreed that a solid nozzle guide vane assembly would be impracticable and, therefore, some method of individual root fixtures was required.

1. Their first attempt was to form a base from pressed metallic powder but this was not successful due to the difference in the rates of expansion between the blade and base at elevated temperatures.

2. A high temperature steel foot containing a slot slightly larger than the blade profile (Fig. V) and the blade retained by a silver-copper solder was the second proposal. This method of locating the stationary blades was not satisfactory at high temperature due to the low melting point of the solder.

3. A foot built up by spraying metal on the base of the blade was the third method but this procedure was discouraged due to the length of time required for manufacture.

4. The method found most suitable was similar to that mentioned in (2) above with the exception that a powdered steel was used in place of the solder (see Fig. VI). This powder was pressed firmly in place and baked.

Each foot or blade base was cone shaped and, although no drawings had been prepared for a complete ring, it was proposed to locate these segments between flanges as shown in Fig. VII. With proper cooling it was felt that this method (4) of locating guide vanes would prove satisfactory.

VII - Conclusions.

1. Investigations on ceramic materials for use in gas turbine engines did not commence until 1941. Between 1941 and 1944 this work had the lowest priority and a great deal of time was lost in obtaining materials from the manufacturers.

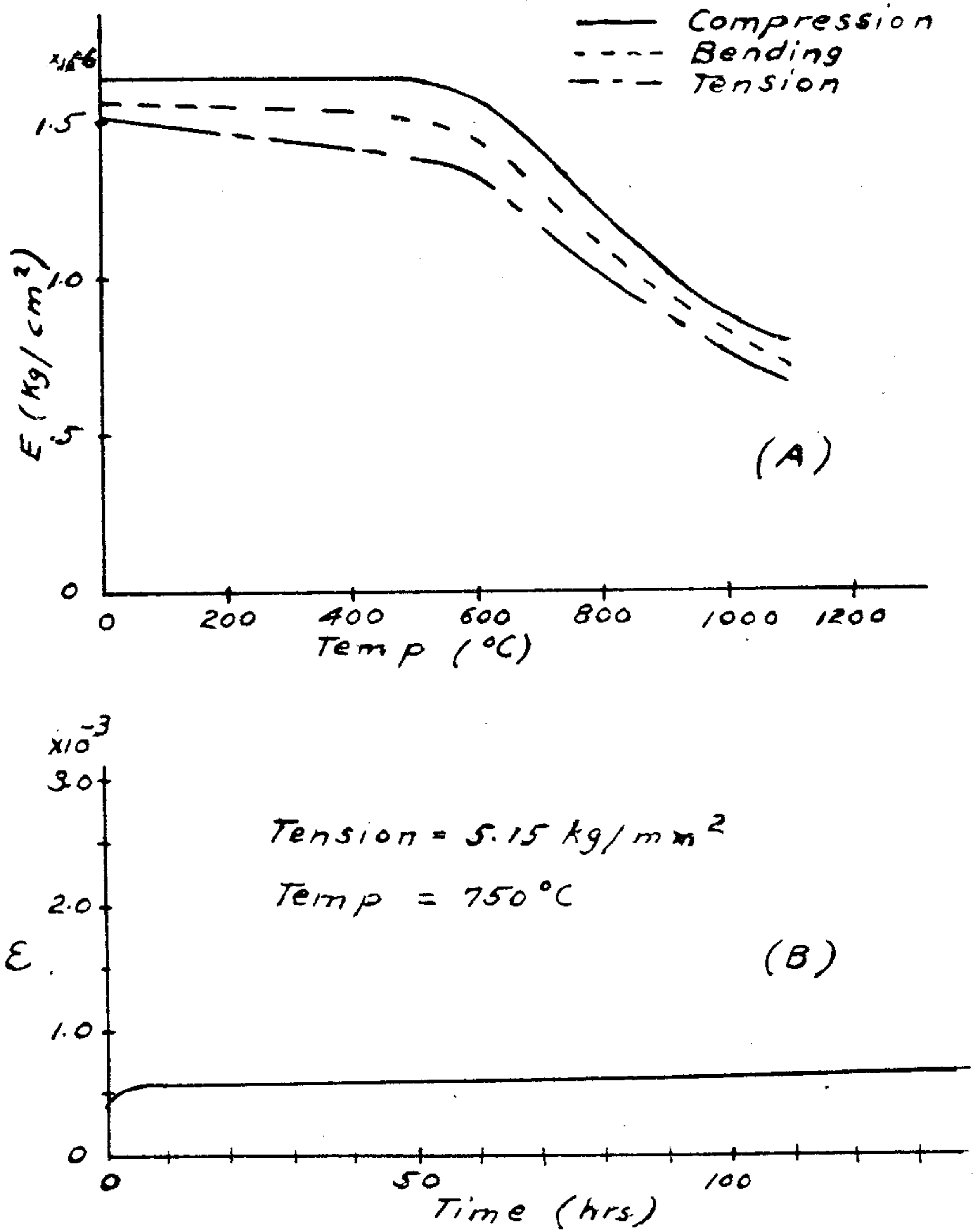
2. In 1944 their priority was raised but during this year the manufacturers in the large cities were working under extreme difficulties as a result of the allies effective bombing.

3. Due to the low ultimate tensile strength of ceramic materials they are not suitable for turbine blades mounted externally on a rotating drum or wheel.

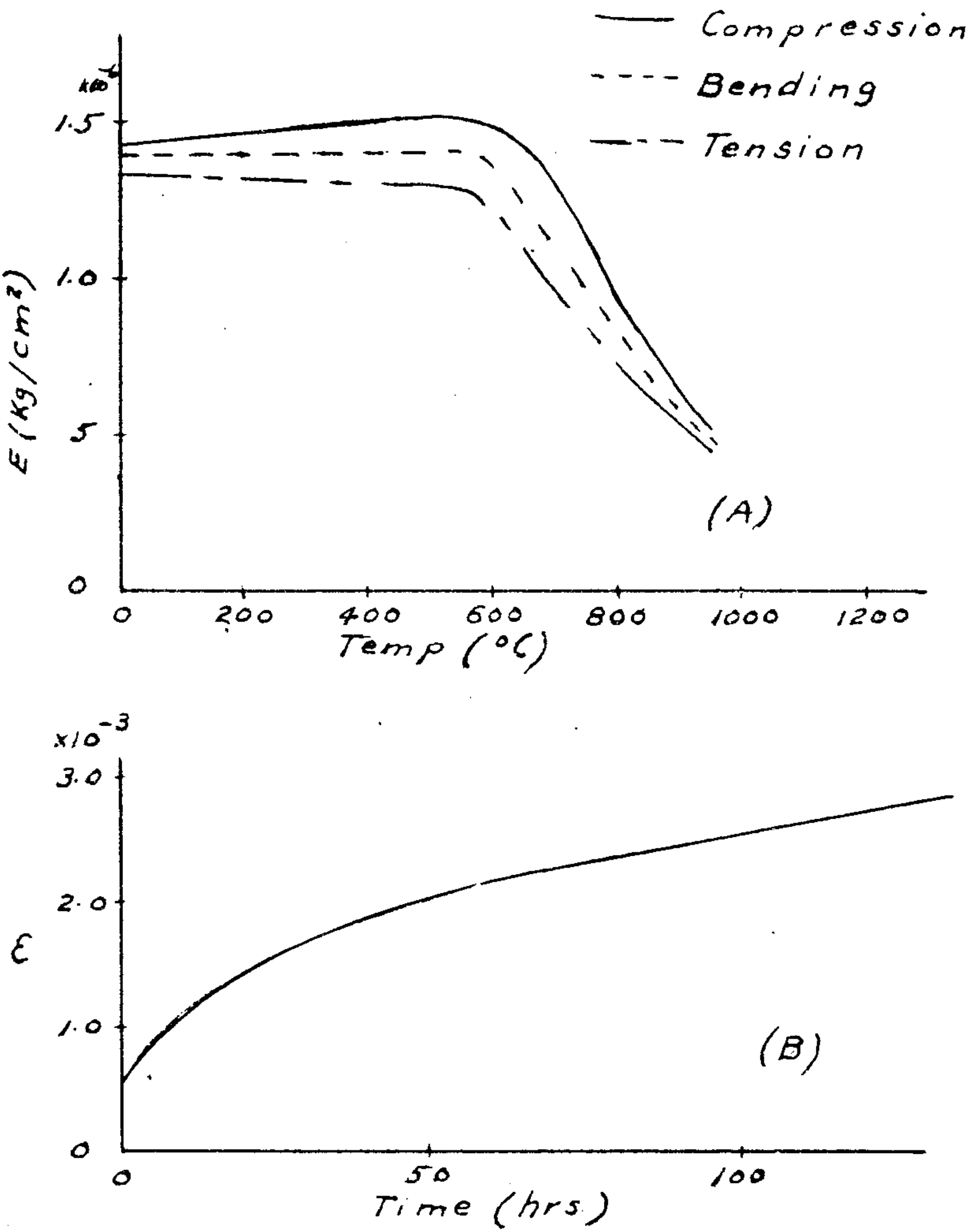
4. Homogeneous material, such as $Al_2 O_3$ and Be O, failed due to sudden changes in temperature. A mixture of $Al_2 O_3$ and Fe, although difficult to form, appeared to be the most promising.

5. If LFA had continued with research for another year and the difficulties mentioned in (1) and (2) above were eliminated, they would probably have developed stationary turbine blades suitable for operation up to 1200°C

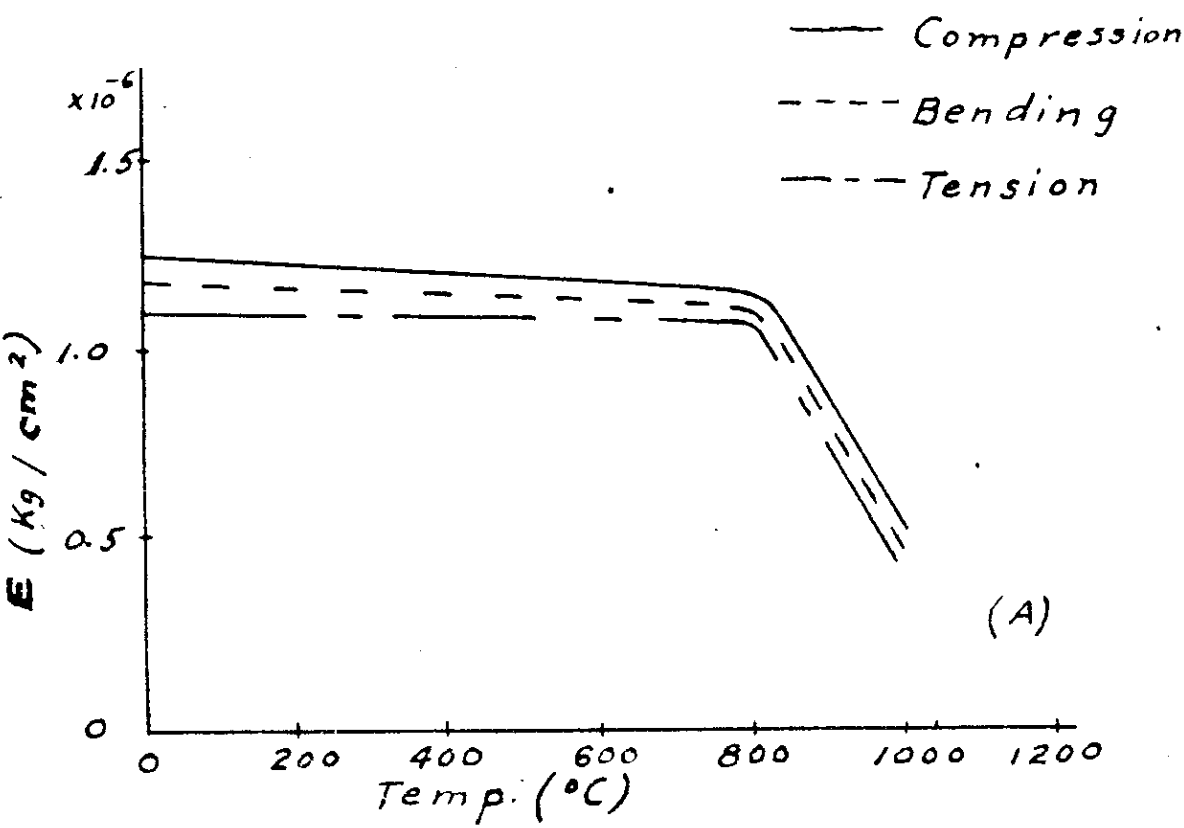
6. The ultimate aim of those persons responsible for engine research at LFA was to design and construct a gas turbine engine using ceramic stationary blades and a water cooled axial turbine operating at 1200°C and 20,000 R.P.M.

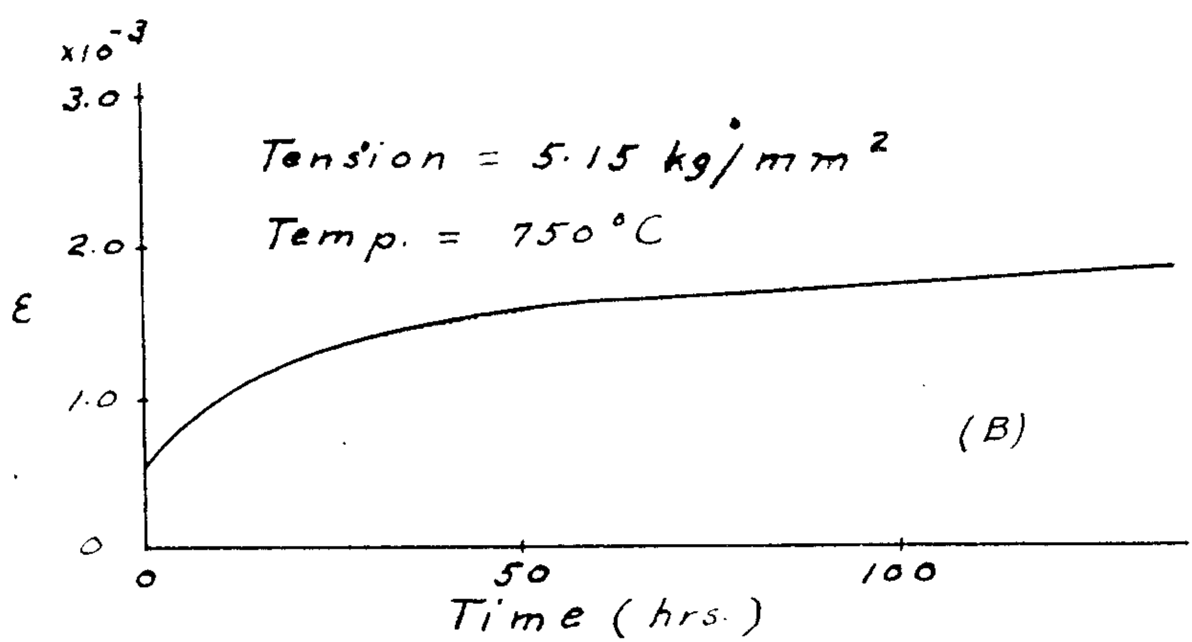


SILLIMANIT 9i   Fig I

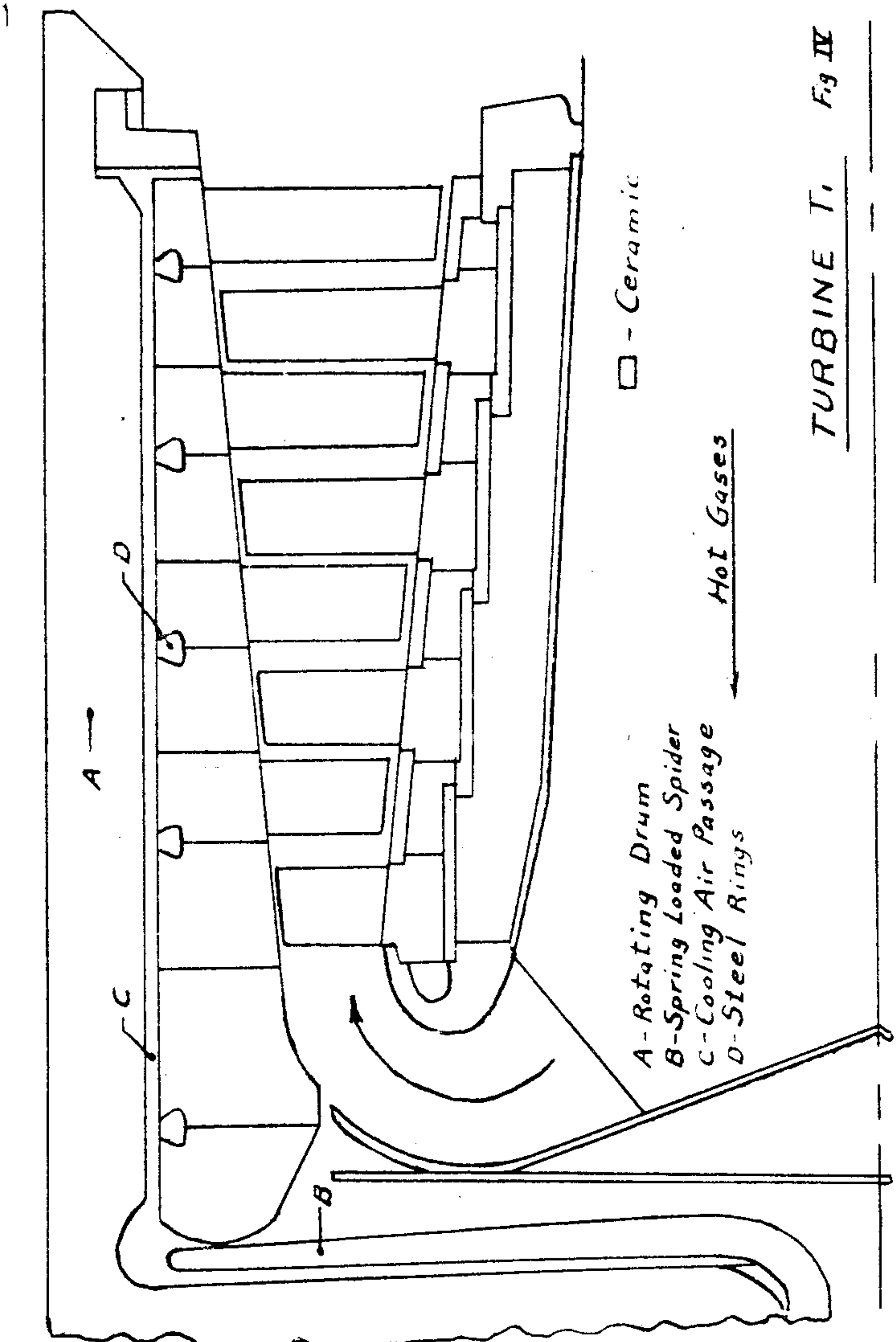


SILLIMANIT 10a   Fig II

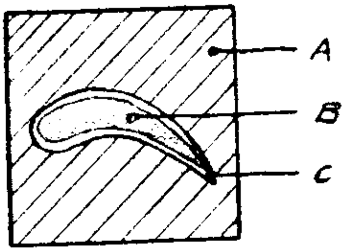




FREQUENTA - Fig. III



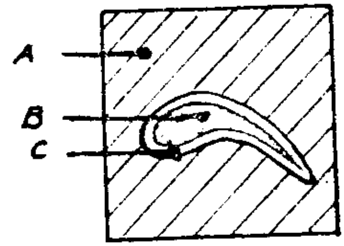
TURBINE T_1 Fig IV



A - Blade Base
B - Blade
C - Copper-Silver Solder

Section of Blade Base

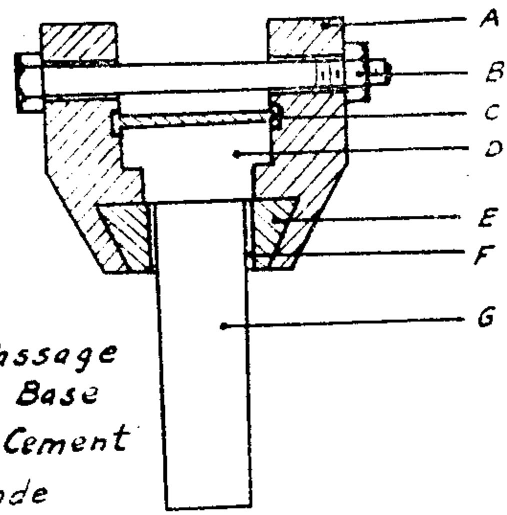
Fig V



A - Blade Base
B - Blade
C - Steel Powder

Section of Blade Base

Fig. VI



A - Flange
B - Bolt
C - Plate
D - Cooling Air Passage
E - Steel Blade Base
F - Powdered Steel Cement
G - Ceramic Blade

Proposed Stator Blade Fixture - Fig VII