CoA. M and P Memo 9

July, 1963

THE COLLEGE OF AERONAUTICS

DEPARTMENT OF PRODUCTION AND INDUSTRIAL ADMINISTRATION

A progress report on the application of numerically controlled grinding to the improvement of the fatigue strength of highly stressed ground gears

- by -

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INTRODUCTION

During the manufacture at the Bristol Aeroplane Works, of the research Aircraft, Bristol 188, difficulty was experienced when attempting to grind sheets of stainless steel (spec. REX 448). The size of the sheets was 7 feet by 5 feet. A surface finish of not more than 10 micro inch CLA together with a thickness tolerance of ± 0.0002 inches was called for. This problem was put to a number of production engineering research establishments, one of which was Cranfield. It was during the research work to find a solution to the above problem that a numerical method of evaluating the performance of grinding wheels, coolants, and the machinability of different materials was developed. This has now been further developed to enable the cause of the limitations in any grinding process to be diagnosed.

The new method of evaluation of a grinding wheel or a wheel coolant combination gives the maximum grit loading, which may be applied and the life per redress of the surface of the wheel at this loading. When a wheel is used under the maximum loading, the grinding process sounds very much less harsh than when grinding in the normal way. That it so is shown clearly in figure 1, where the specimen of REX 448 was ground under the new condition and the normal method. It can be seen that the mechanical deterioration is very reduced when using the new method.

The application of the new grinding method to the finishing of highly stressed aircraft gears.

There has been little appreciable progress made in the rate at which highly stressed components have been finish ground.

During the last decade most of the increase of rate of production has been achieved by more efficient sequencing and indexing of the machine tools. It is also established that the normal grinding method leaves the surface of the component in a state of residual tensile stress.

The magnitude of the stress is to a large extent determined by the efficiency of the grinding procee and can be as low as 30,000 p.s.i. with a general average of 60,000 to 70,000 p.s.i. Under adverse grinding conditions the U.T.S. of the material is exceeded and surface cracking occurs.

Recent fatigue tests carried out in gear tooth manufacture, from a case carborised steel and finished by grinding, showed a general depreciation of 25% with some results. 48% below the anticipated performance when compared with underground gears. The application of the new grinding method to the finish grinding of aircraft gears was undertaken to achieve the following result:

1. To select the most efficient grinding wheel commercially available, and if possible, improvement of this wheel. Also to select and improve upon the most effienct coolant to be used in combination with the chosen wheel.

2. To suggest the working conditions under which the wheel and coolant are to be used to result in the least deterioration of the ground surface due to the grinding process.

The selection of the most efficient grinding wheel and coolant.

Tests were carried out to select the most efficient grit material. The results of these tests show that white alumina oxide was best with red alumina oxide (added chromium). a very close second best for ability to penetrate the test piece material (case hardened S.107). The rate of wear on the grits was equal. The white alumina grit was chosen. Bond and porosity was then varied to select the most efficient grit bond and hardness combination. The final results of these tests were that a Universal Grinding Wheel Co. Ltd., specification W.A. 60 J.V. was most efficient. This wheel was used to select an efficient coolant, from a wide range tested. The Manchester Oil Refinery Dolphin No. 1 proved best. It gave results of best surface finish, longest grit life with a cool component, at maximum metal removal rates. Later tests show that the surface residual stress was also at the lowest when this coolant is used. (Note: The method of carrying out the above tests are described in detail in C of A Note 143)

The selected grinding wheel and coolant combination is capable of a maximum depth of cut per grit (E C of A Note 143) of 0.0006 ins. The gear material (S.107) fully heat treated was ground with a grit load of 0.00045 ins. 0.00035 ins., and 0.0002 ins. Graph 6 shows the residual stress versus depth under surface of an unground specimen. From this it is seen that a compressive stress of 68,400 p.s.i. exists in the surface to a depth of 0.0005 ins. when violent changes in stress occur at sub-surface levels. A number of these specimens have been subjected to the stress calculation and all show this general pattern. The magnitude of the residual stress level varies between 98,000 p.s.i. and 40,000 p.s.i.

Graph Fig 7 shows that this residual compressive stress is changed to a residual tensile stress of approximately 40,000p.s.i. when the component is ground using 75% of maximum pneumatic grit loading i.e. 0.00045 ins.

A further reduction to 53% of maximum grit load to 0.00035 ins reduces this residual tensile stress to 10,000 p.s.i. to 15,000 p.s.i. see Fig. 8 and 9.

When the grit load is 33% of the maximum possible there is no residual tensile stress. The surface of the gear tooth is preserved in a state of residual compressive stress. Figures 10 to 13 show this presented graphically There are three major significant factors revealed by these tests. These are:

1. That it is possible, by using the numerical evaluation of the grinding process to finish grind highly stressed components and retain any original desirable residual stresses, or produce very low tensile residual stresses in the order of 4,000 p.s.i. to 8,000 p.s.i

2. That any grit load approximating to maximum possible grit load will cause high residual tensile stresses to be induced into the surface layer of material.

3. When these high surface residual tensile stresses do exist they are in a layer of approximately 0.0015 to 0.0025 ins and there is very high and undesirable stress differential between layers at the above sub-surface depth. This stress differential may be assumed to contribute to the failure of ground surfaces which are heavily stressed in the shape of a scale, the failure being initiated sub-surface at the stress differential level.

Graphs 6 to 13 show violent fluctuation in residual stresses at sub-surface levels. Initially two causes for these fluctuations were assumed:

1. They were caused by the heat treatment to which the material had been subjected.

2. There was serious banding in the material (non-homogenity of the material)

To eliminate the first of the above assumptions, specimens cut from the original test pieces were given further heat treatment as follows:

2 hrs soak at 150°c (low temperature stress relief)

48 hrs soak at 150°c (" " " ")

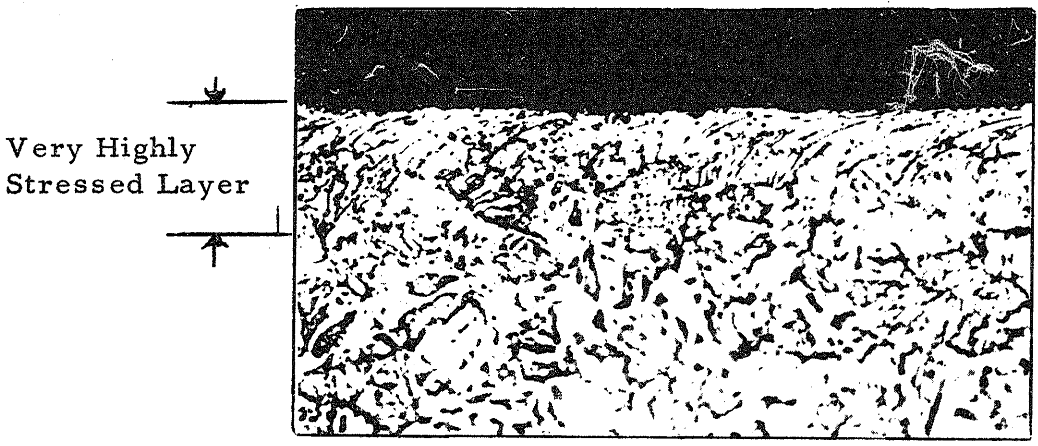
48 hrs soak at 200°c (" " " ")

This treatment reduced the magnitude of the sub-surface residual stresses to approximately 30% of the original but did not change the pitch at which they occurred (see graphs 14 to 17). (Note 14 has a change in stress magnitude of 16,000 p.s.i. even after the 48 hour at 150°c stress relieving treatment)

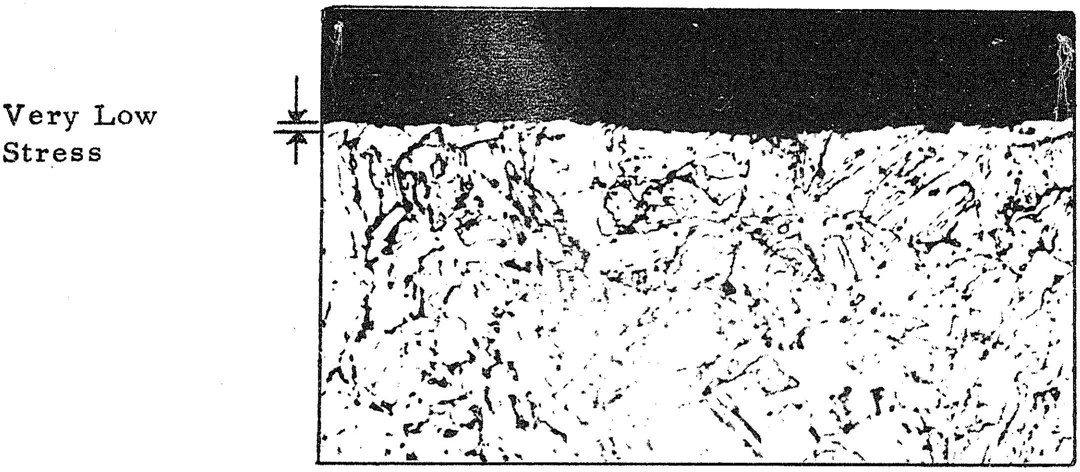
Further investigation and confirmation of suspected banding was revealed by micro-photographs produced by the Materials Department of the College of Aeronautics these are included fig. 2 and 3. Fig. 1 shows the section from which the micro-photo section was taken. (The disorderly numbering of the figures is due to the use of plates which have been used for earlier progress reports being used).

Three samples of this material has been supplied for the grinding tests. All have suffered from this metallurgical fault. Work is continuing to produce reliable information on the state of the residual stress in the surface after finish grinding, it is intended to present this information in graphical form from which the condition of the surface of the component will be predictable at any time during the life of the surface of the grinding wheel.

MATERIAL REX 448 STAINLESS STEEL
MAGNIFICATION 1,000 TIMES



SPECIMEN GROUND NORMALLY



SPECIMEN GROUND AT 0.00045 ins. GRIT LOAD
WHEN MAXIMUM GRIT LOAD IS 0.0006 ins.

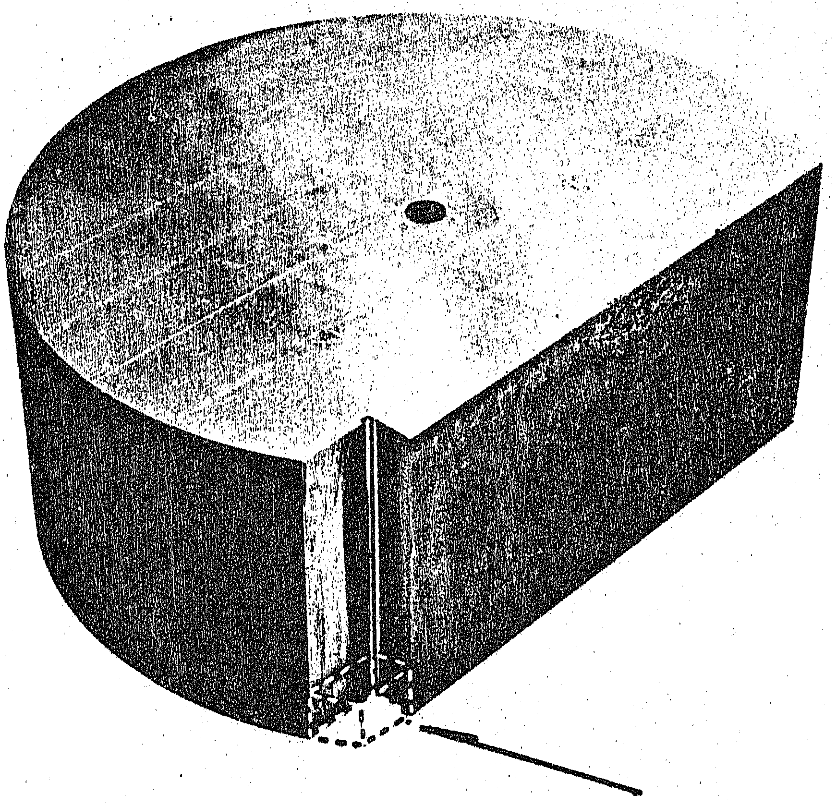


Fig. 1.

S. 107 Stock. Showing location of microstructure sample.

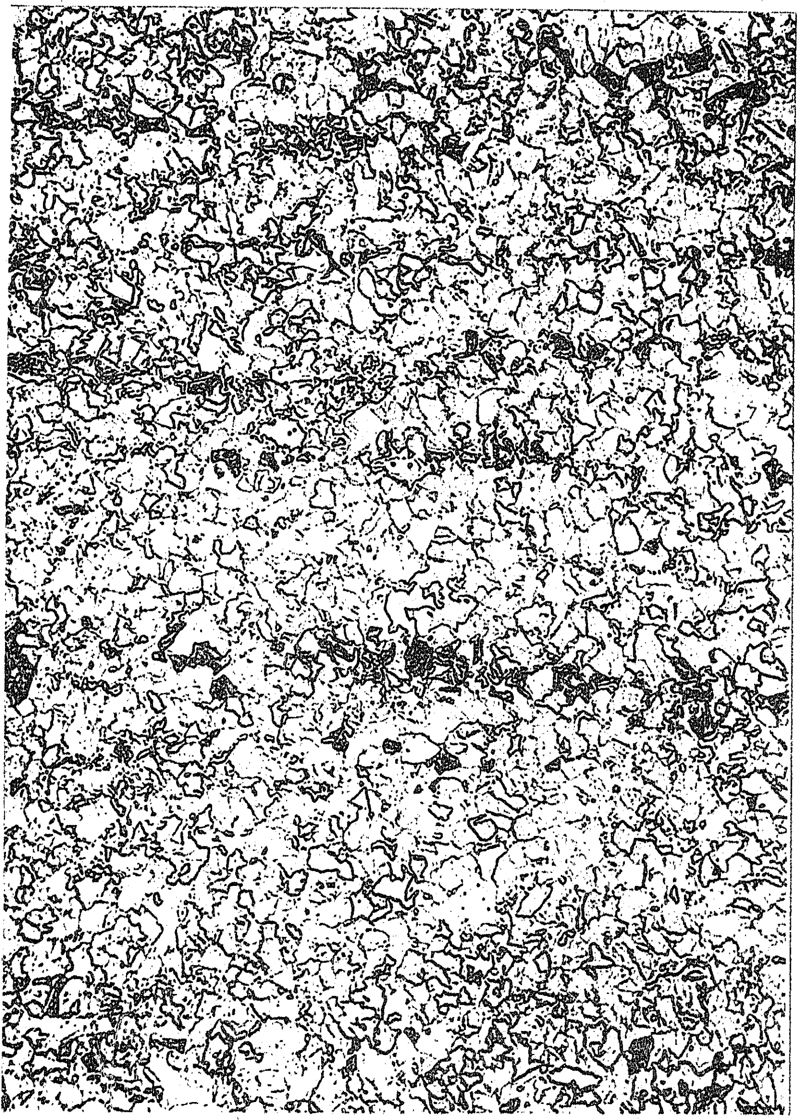


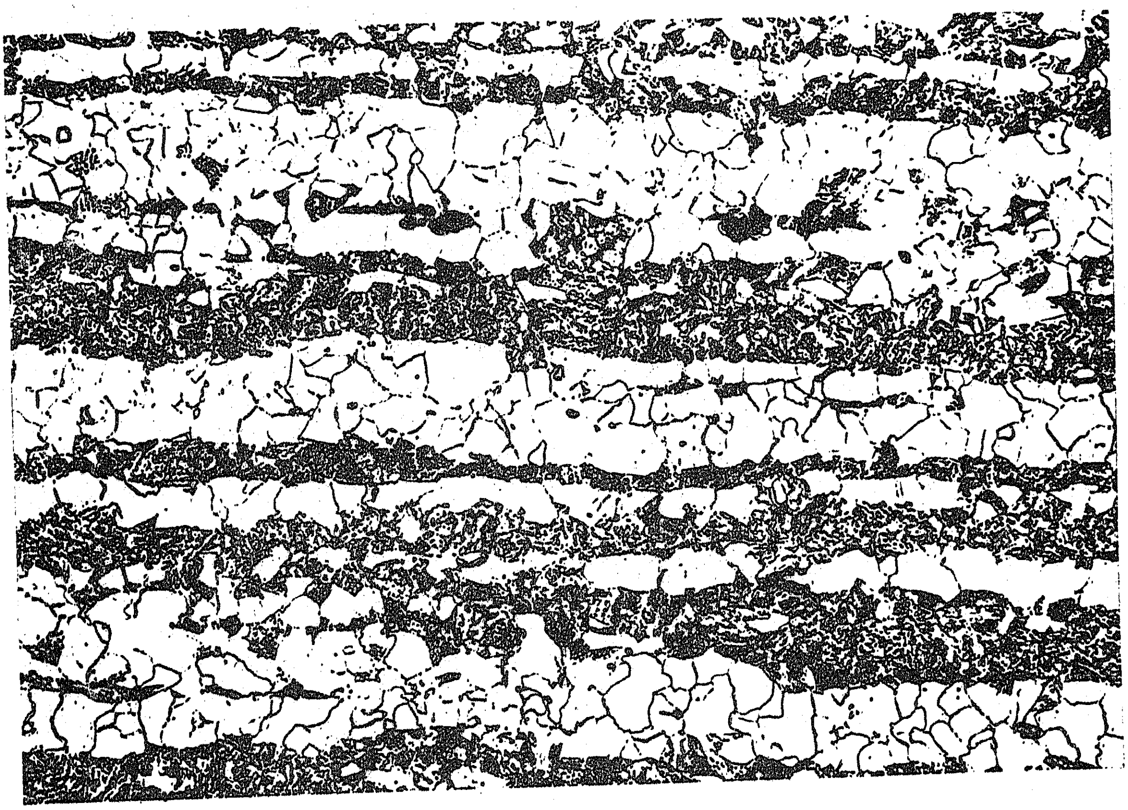
Fig. 2.

Banding microstructure showing the pitch of the banding.

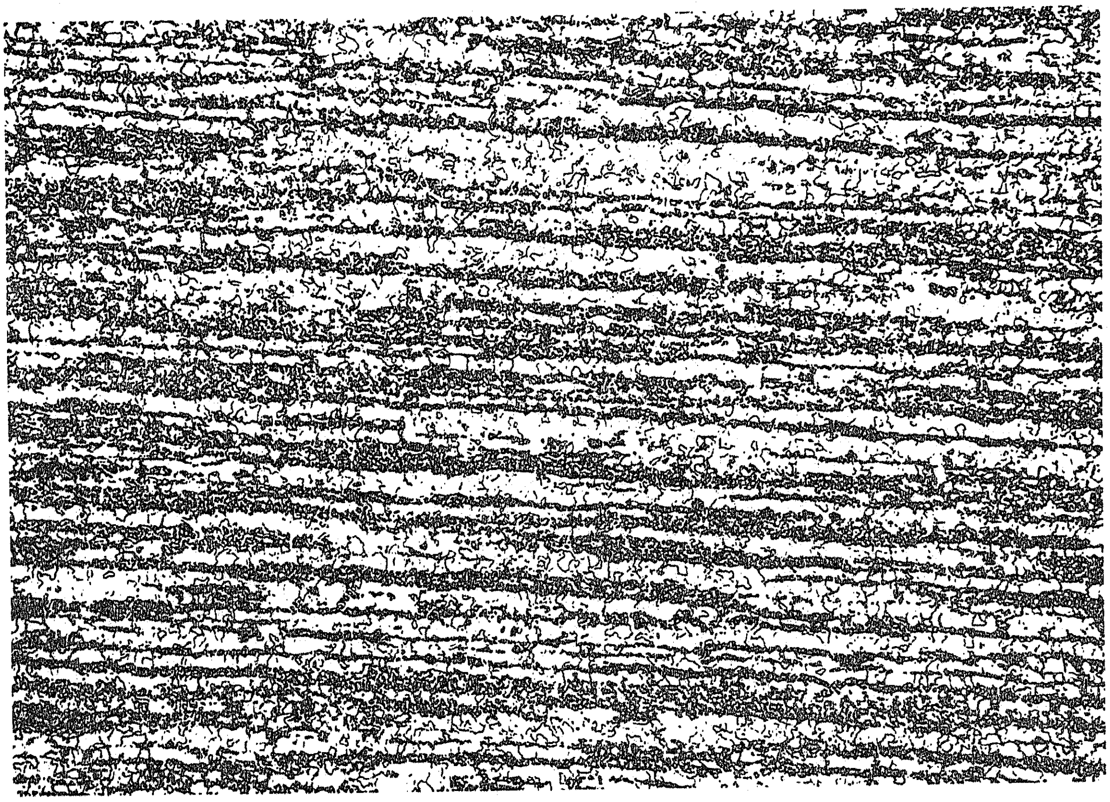
Mag. x 75.

Fig. 3.

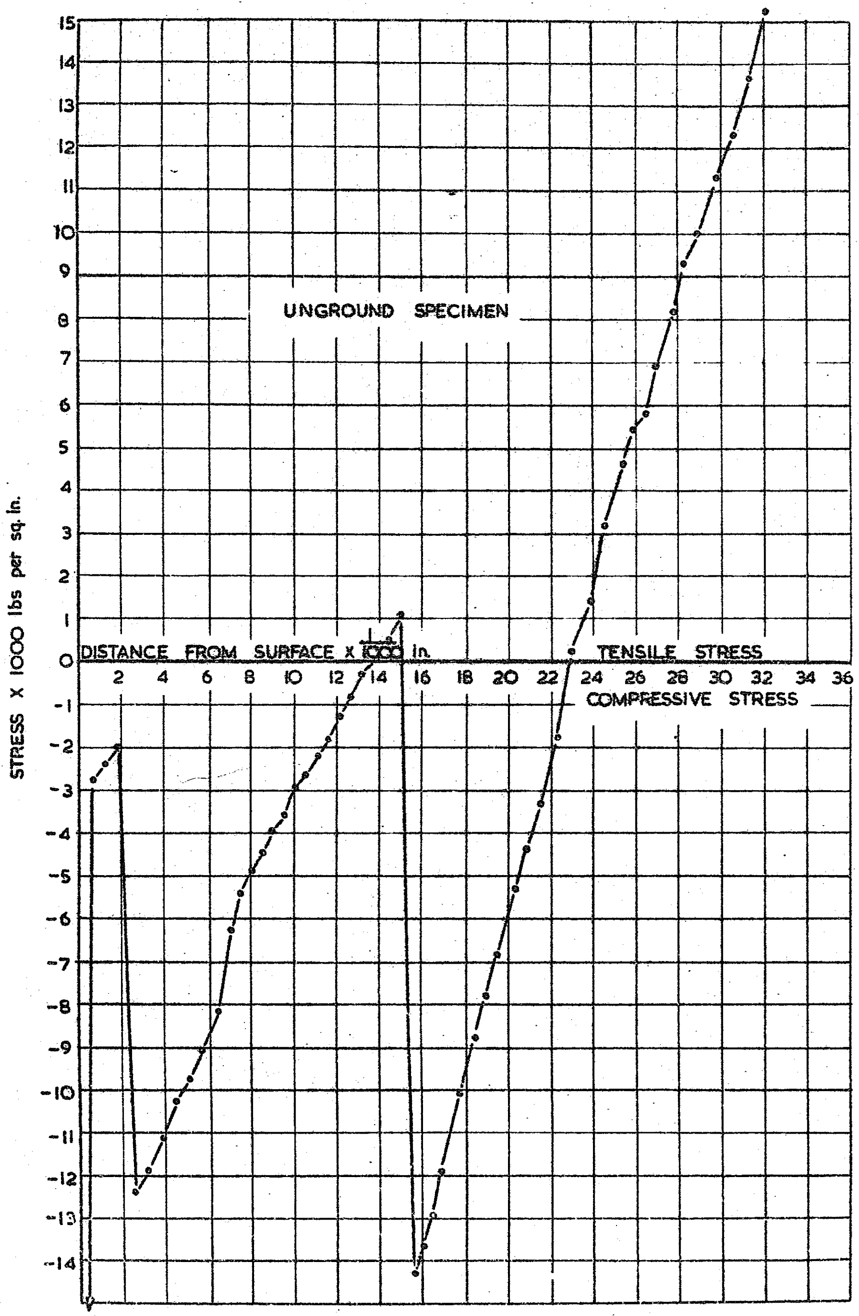
Detail of the banded structure. Mag. x 300.



SAMPLES OF S.107 AS SUPPLIED IN SECTION $\frac{3}{4}$" SQUARE
TO THE COLLEGE OF AERONAUTICS MATERIALS DEPARTMENT
MAGNIFICATION X 200.



SAMPLES OF S.107 AS SUPPLIED IN SECTION $\frac{3}{4}$" SQUARE
TO THE COLLEGE OF AERONAUTICS MATERIALS DEPARTMENT
MAGNIFICATION X 75



TO 68,400 lbs per sq in.

FIG. 6.

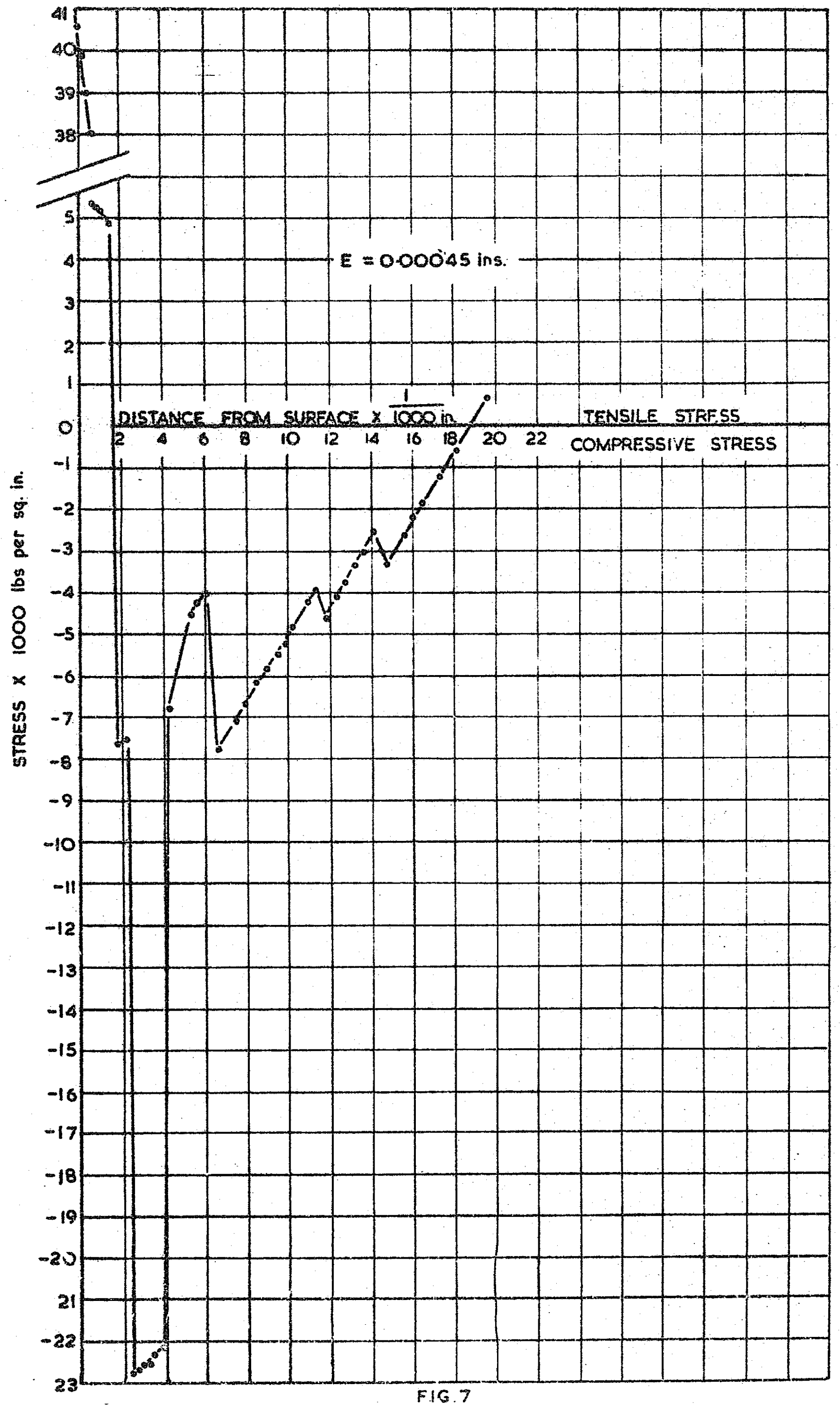


FIG. 7

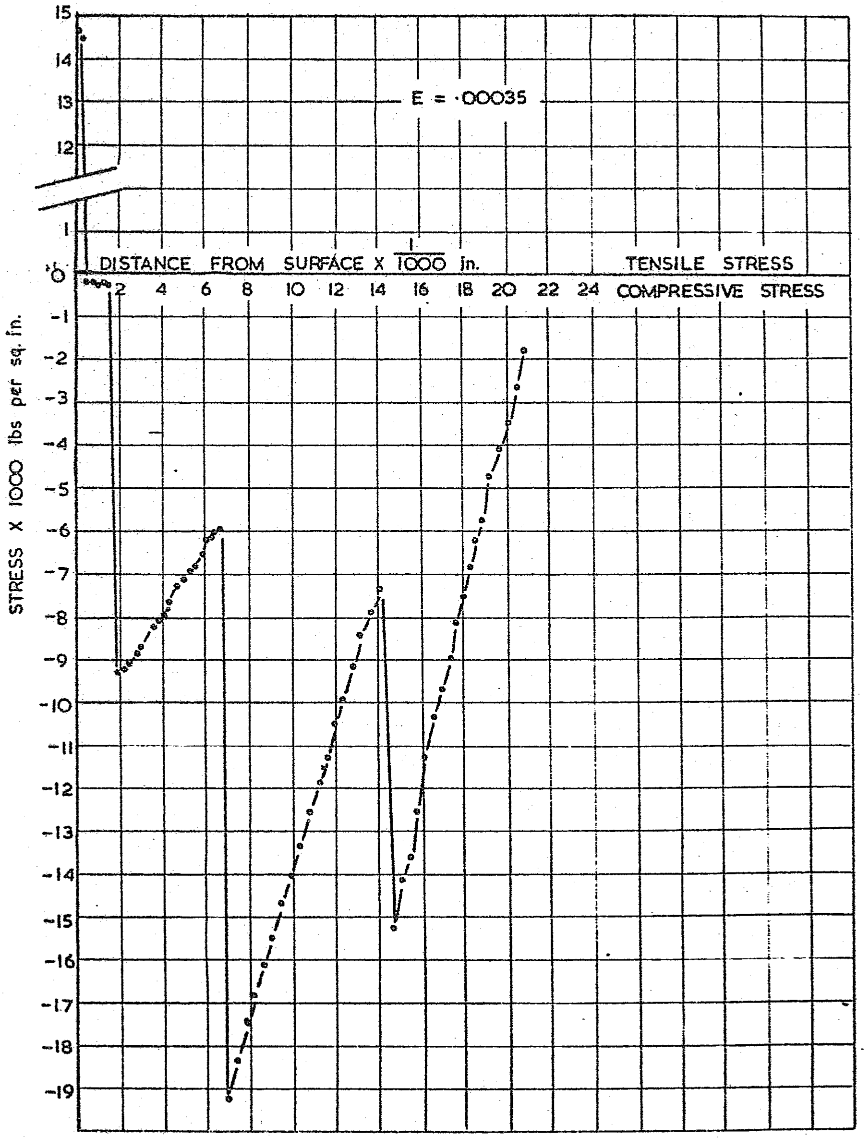

E = ·00035
DISTANCE FROM SURFACE X 1/1000 in.
TENSILE STRESS
COMPRESSIVE STRESS
STRESS X 1000 lbs per sq. in.
15
14
13
12
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
2
4
6
8
10
12
14
16
18
20
22
24

FIG. 8.

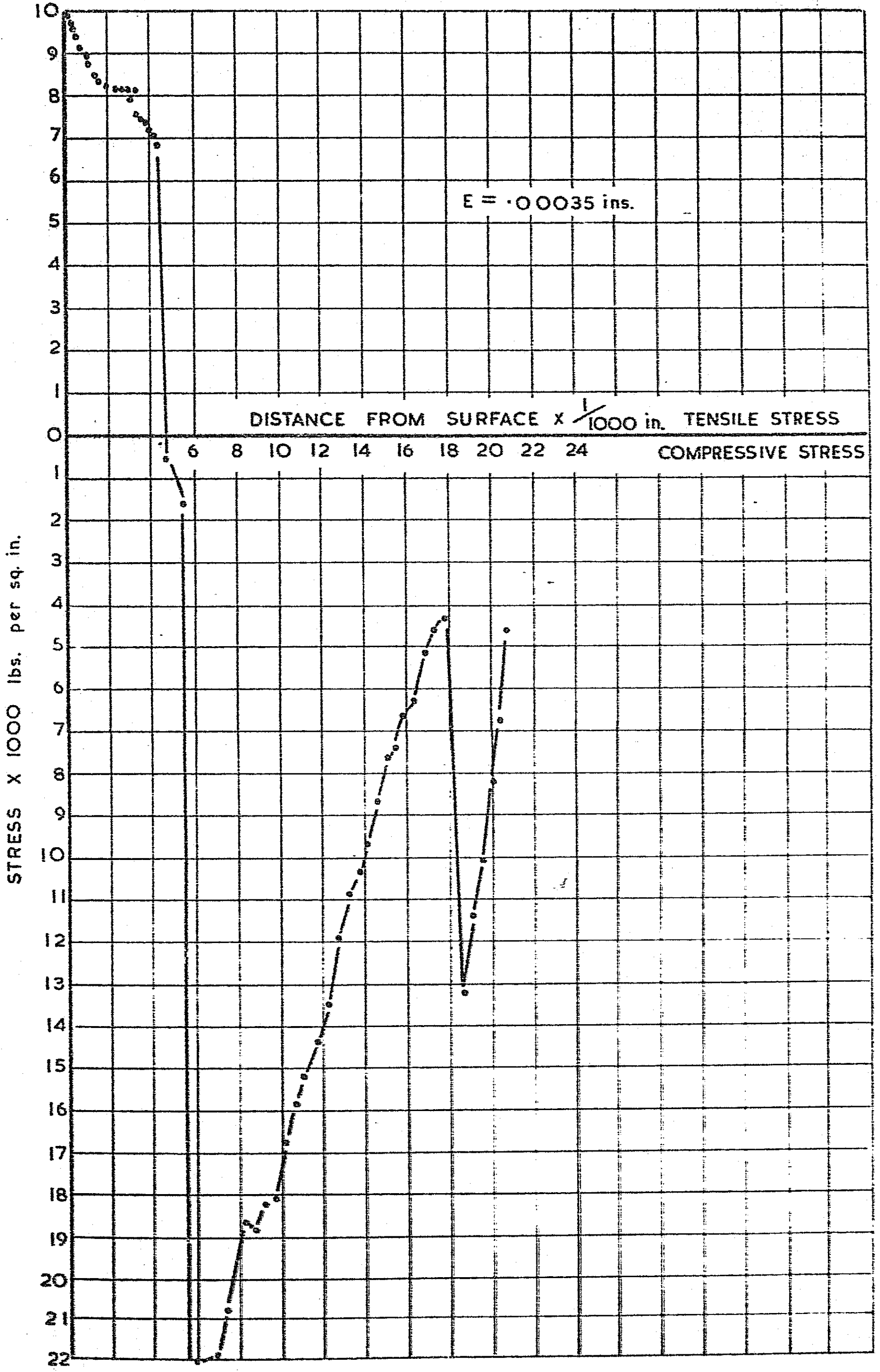

E = ·00035 ins.
DISTANCE FROM SURFACE X 1/1000 in.
TENSILE STRESS
COMPRESSIVE STRESS
STRESS X 1000 lbs. per sq. in.
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
6
8
10
12
14
16
18
20
22
24

FIG. 9.

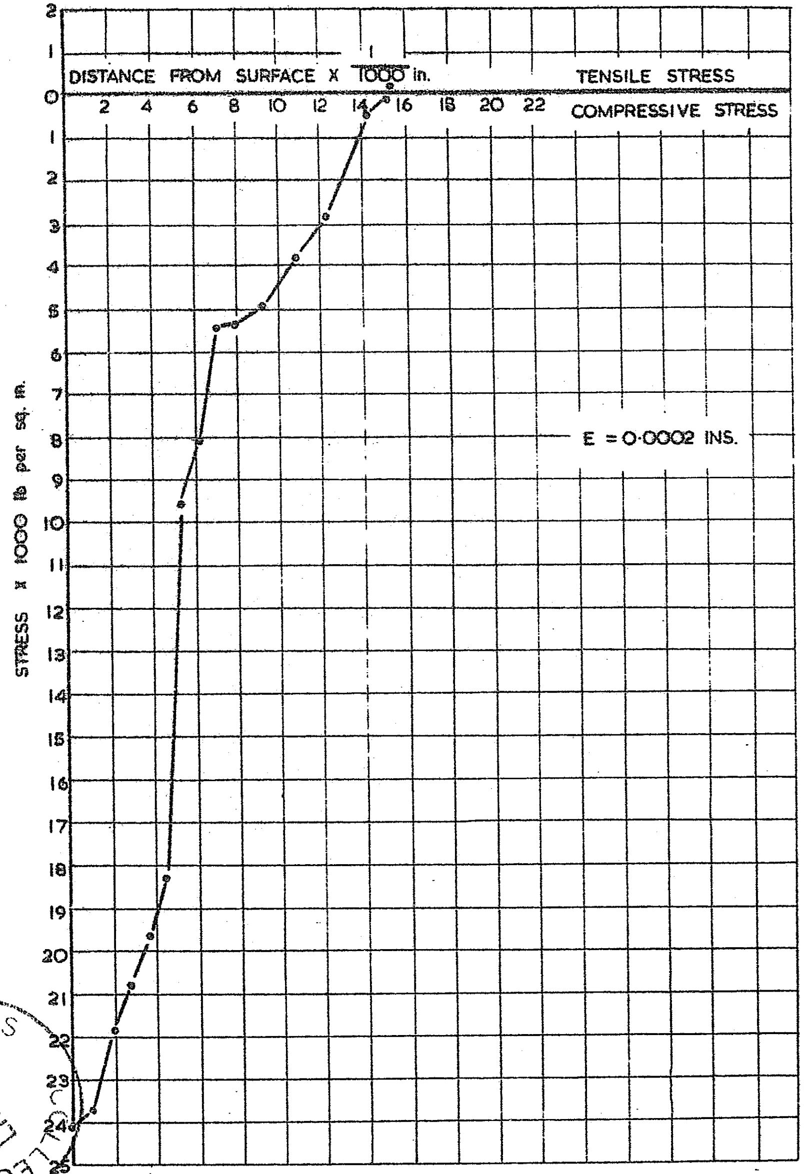

DISTANCE FROM SURFACE X 1/1000 in.
TENSILE STRESS
COMPRESSIVE STRESS
2 4 6 8 10 12 14 16 18 20 22
STRESS X 1000 lb per sq. in.
2 1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
E = 0·0002 INS.

FIG. 10.

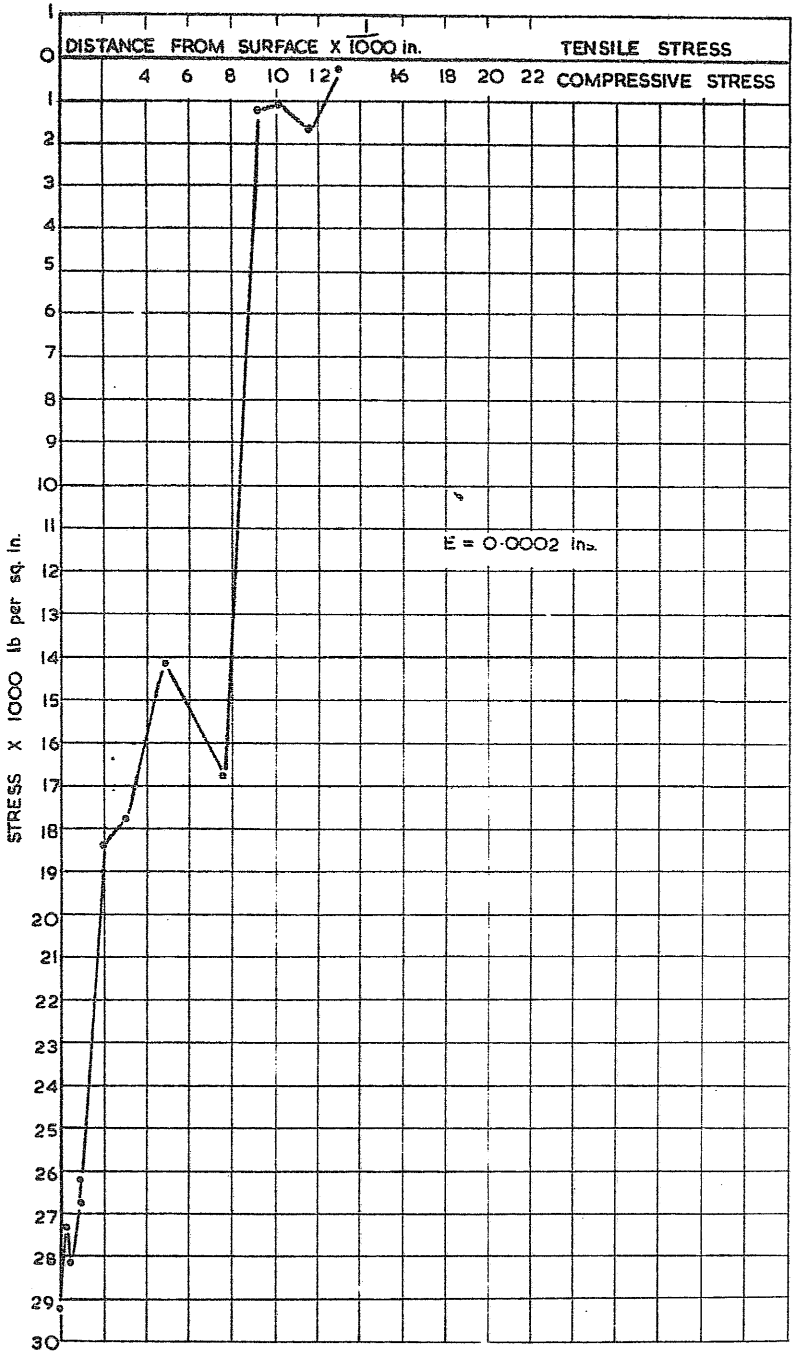
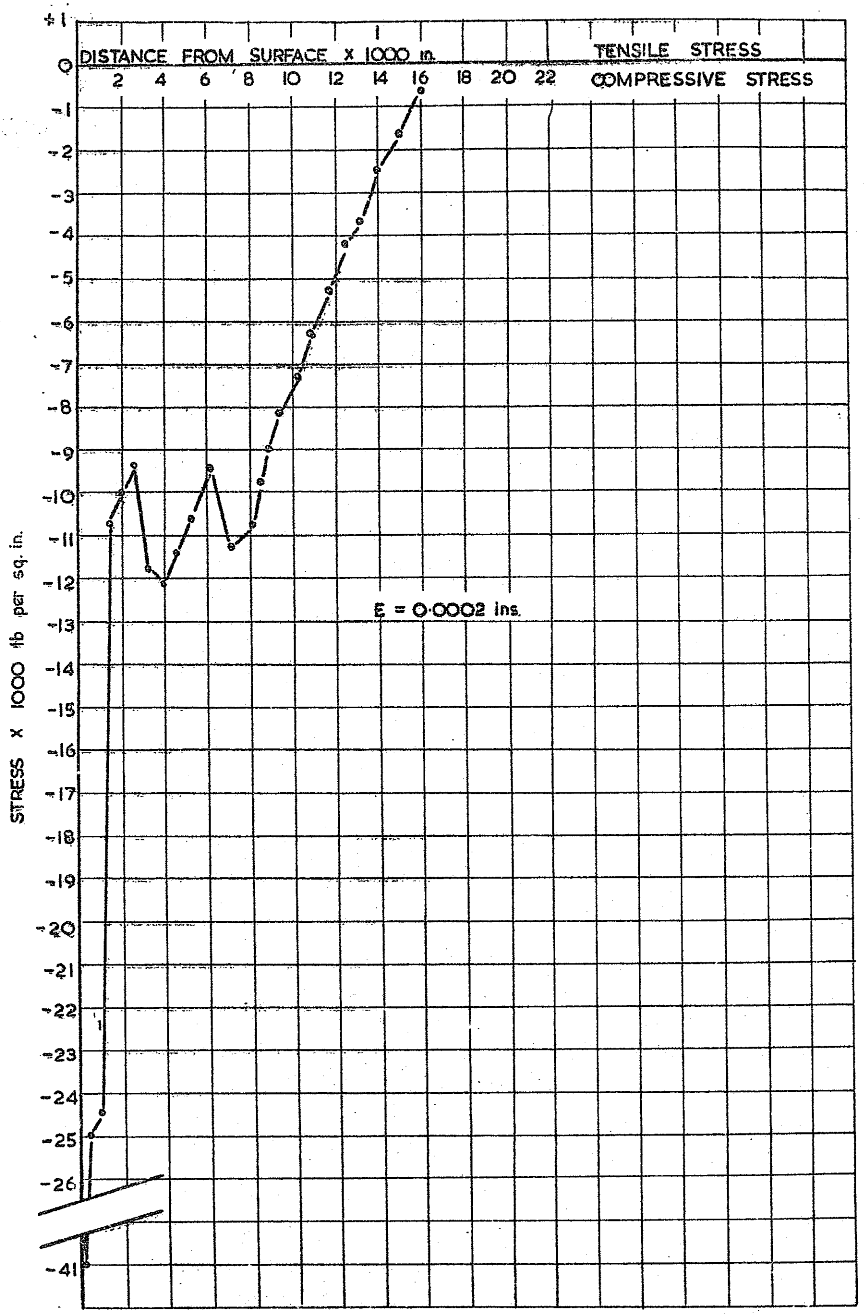
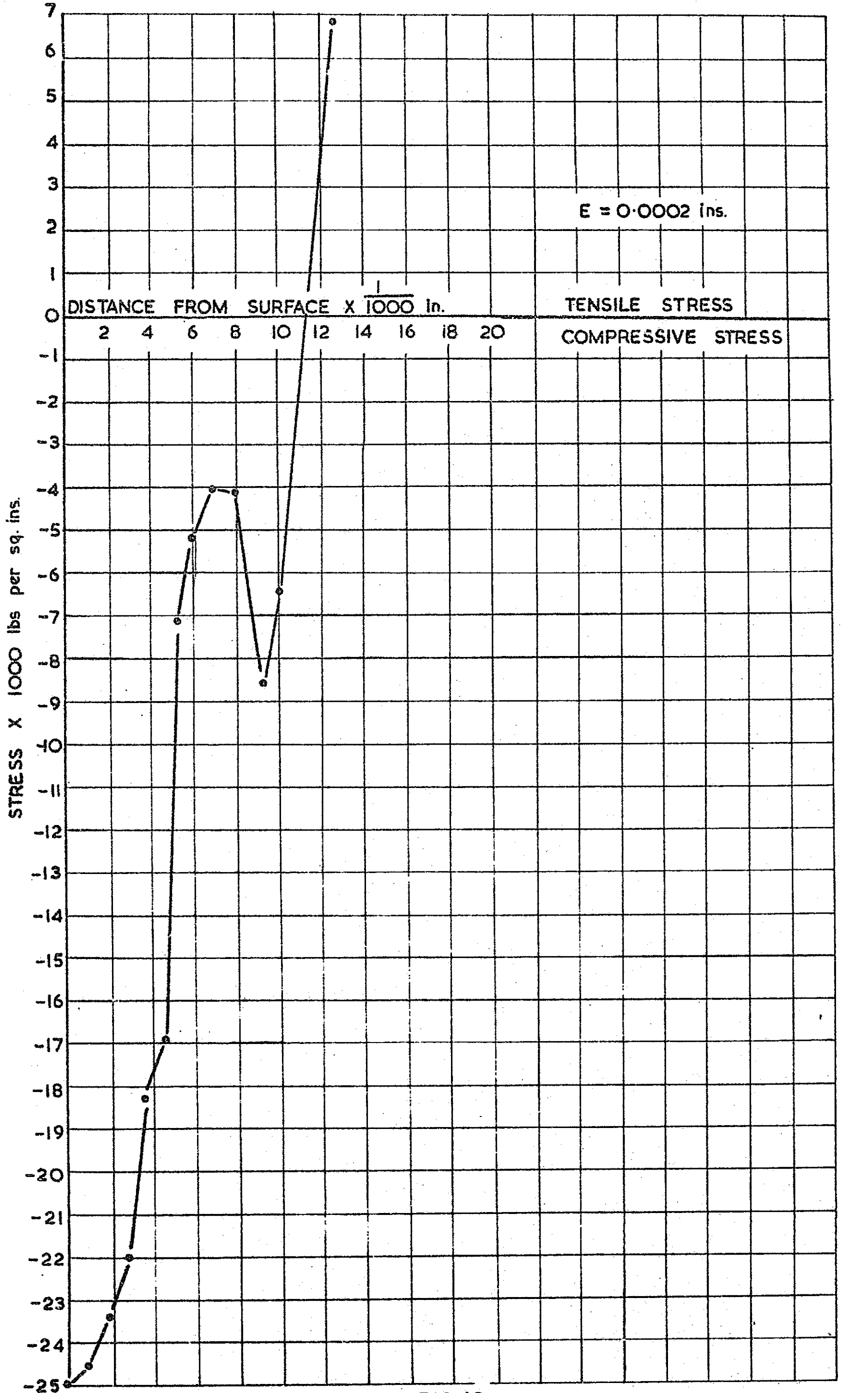

DISTANCE FROM SURFACE X 1/1000 in.
TENSILE STRESS
COMPRESSIVE STRESS
4 6 8 10 12 16 18 20 22
STRESS X 1000 lb per sq. in.
1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
E = 0·0002 ins.

FIG. 11.



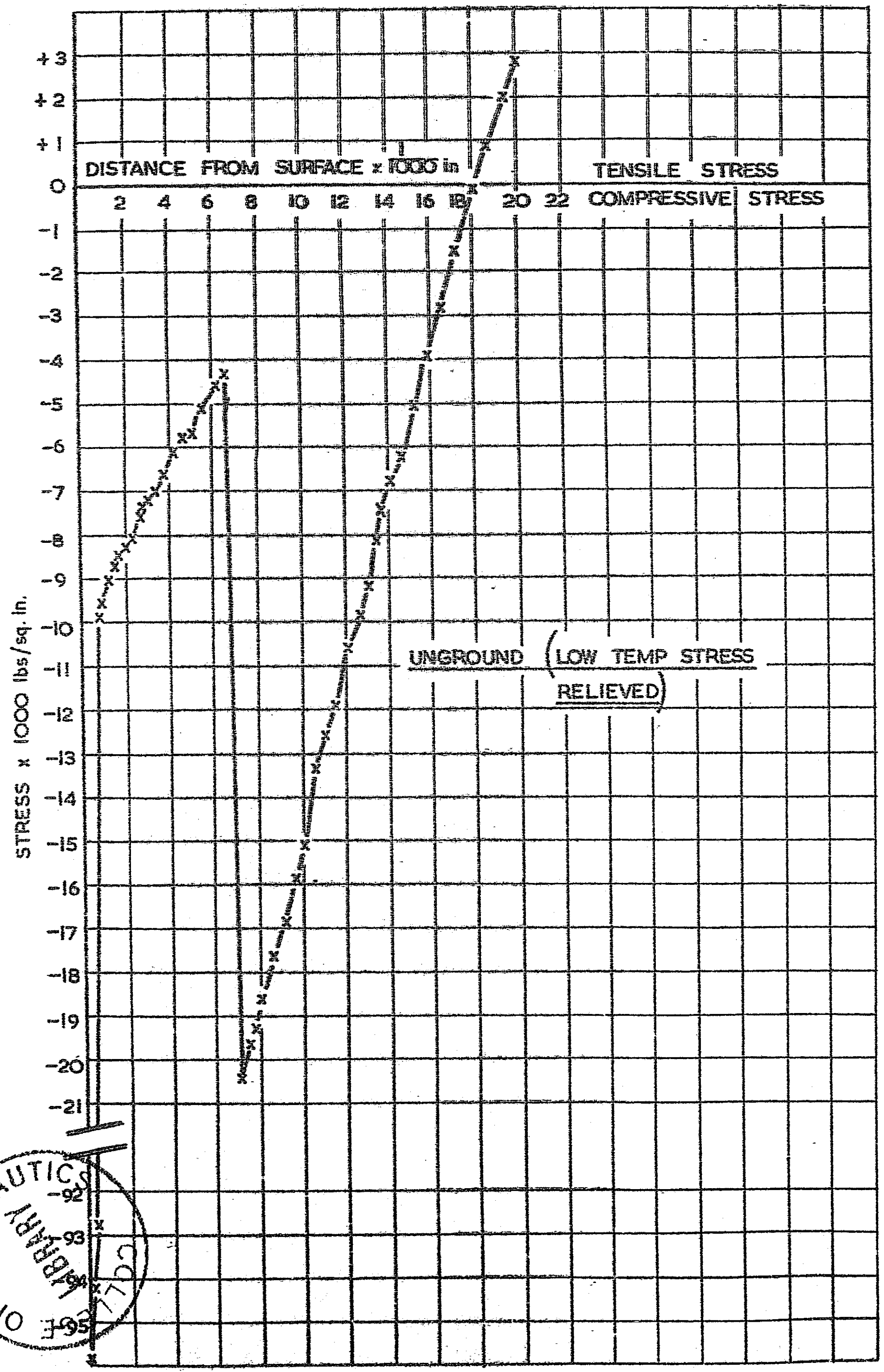
+1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
-26
-41
STRESS X 1000 lb per sq. in.
DISTANCE FROM SURFACE X 1000 in.
2 4 6 8 10 12 14 16 18 20 22
TENSILE STRESS
COMPRESSIVE STRESS
E = 0·0002 ins.

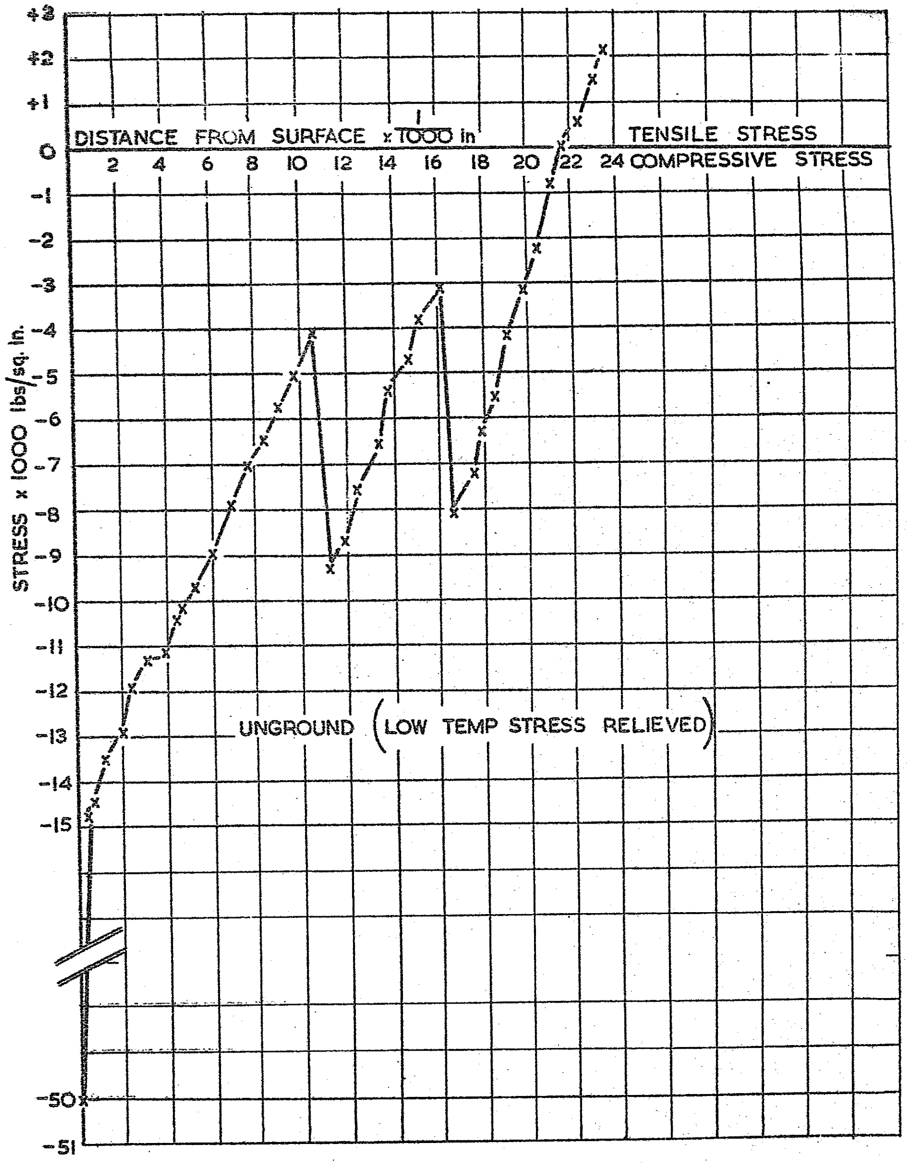
FIG. 12.

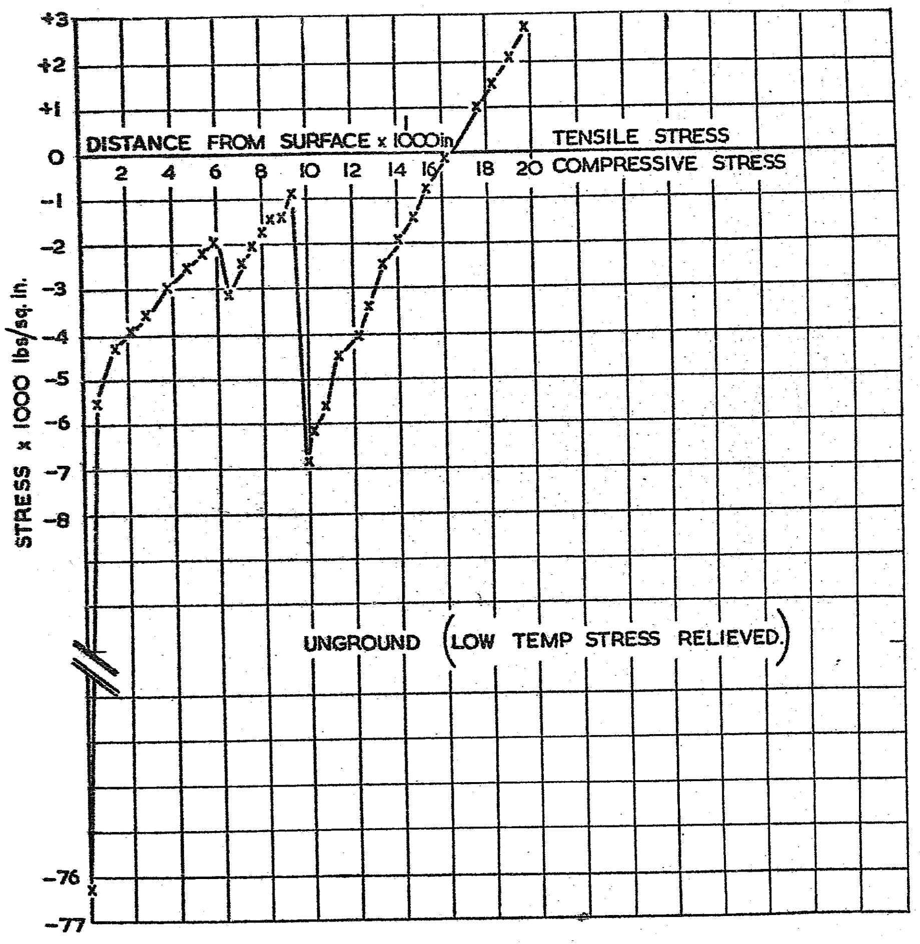


7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
STRESS X 1000 lbs per sq. ins.
DISTANCE FROM SURFACE X 1/1000 In.
2 4 6 8 10 12 14 16 18 20
TENSILE STRESS
COMPRESSIVE STRESS
E = 0·0002 ins.

FIG. 13.


DISTANCE FROM SURFACE x 1/1000 in
2 4 6 8 10 12 14 16 18 20 22
TENSILE STRESS
COMPRESSIVE STRESS
STRESS x 1000 lbs/sq. in.
+3 +2 +1 0 -1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21
-92 -93 -94 -95
UNGROUND (LOW TEMP STRESS RELIEVED)


DISTANCE FROM SURFACE x 1/1000 in
2 4 6 8 10 12 14 16 18 20 22 24
TENSILE STRESS
COMPRESSIVE STRESS
STRESS x 1000 lbs/sq. in.
+3 +2 +1 0 -1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15
-50 -51
UNGROUND (LOW TEMP STRESS RELIEVED)


STRESS x 1000 lbs/sq. in.
+3
+2
+1
0
-1
-2
-3
-4
-5
-6
-7
-8
-76
-77
DISTANCE FROM SURFACE x 1000in
2
4
6
8
10
12
14
16
18
20
TENSILE STRESS
COMPRESSIVE STRESS
UNGROUND (LOW TEMP STRESS RELIEVED.)