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MECHANICAL PROPERTIES OF SOLID AND POROUS STAINLESS STEEL SHEET MATERIAL AT ELEVATED TEMPERATURES

by

J. B. LORD

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Mechanical Properties of Solid and Porous Stainless Steel Sheet Material at Elevated Temperatures *

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J. B. Lord, D.C.Ae.

SUMMARY

A series of tensile tests in the temperature range from 20°C to 1000°C were carried out on three stainless steel sheet materials, namely D.T.D.166B, D.T.D.171 and a woven porous material called Rigimesh.

Values of Young's modulus, secant modulus, proof stress and ultimate stress were determined over the whole temperature range, and values of Poisson's ratio were determined at temperatures up to 500°C. Room temperature tests were also carried out on the woven material at various orientations of the weave.

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* Based on a thesis submitted in partial fulfilment of the requirements for the Diploma of the College of Aeronautics.

CONTENTS

1. Introduction

The work presented in this Note formed part of a thesis entitled "Cooling Techniques for Hypersonic Flight", in which particular attention is paid to the problems associated with cooling of the external surfaces of hypersonic vehicles. For efflux cooling techniques suitable porous structural material is required and an experimental investigation was made using a porous stainless steel known as "Porosint Rigimesh" and having a similar composition to solid steel sheet D.T.D.166B and D.T.D.171. The mechanical properties of these three steels were investigated.

2. Materials

2.1. Solid sheet materials

The 20 s.w.g. D.T.D.166B and D.T.D.171 sheet materials were supplied from stock by Messrs. A.V.Roe & Co. Ltd. These two materials have identical compositions, being chromium-nickel, non-corrodible steels but different mechanical properties due to the fact that D.T.D.166B is supplied in a cold rolled condition while D.T.D.171 is supplied in a softened condition.

2.2. Porous sheet material

The "Porosint Rigimesh" porous stainless steel was manufactured and supplied by Messrs. Sintered Products Ltd., Sutton-in-Ashfield. The material was a nominal 20 s.w.g. and had a porosity rating of 30 microns. The sheet is woven using Firth Vickers Staybrite F.M.B. steel wire which is an 18% Cr.; 8% Ni austenitic steel having a similar composition to the solid sheet materials.

The sheet is manufactured by rolling and sintering a three layer wire mesh which is made rigid by furnace welding the wires of the weave at all contact points. The warp and weft are woven with a 90^{o} cross-over angle for each layer of the weave and adjacent layers are rotated through 90^{o}.

The direction of loading for the elevated temperature tensile tests was along the warp which signifies that the load was taken on a cross-section consisting of warp, weft, warp through the three layers of weave.

3. Test Equipment

3.1. Elevated temperature tensile tests

The overall dimensions of the test specimens were 12" x $2\frac{5}{8}$" with a 2" x $\frac{1}{2}$" gauge length. The specimen incorporated lugs for the attachments of braids to facilitate resistance heating. The heating unit used was based on that developed by the R.A.E. and described in R.A.E. TN. MET.263.

The tensile tests were performed on a rig designed and manufactured by Messrs. A.V.Roe & Co. Ltd. who kindly gave permission for its use. The rig is a tensile test unit for sheet material, using rapid heating and loading, which gives a direct X-Y recording of the load-deflection curve for the material.

3.1.1. Poisson's ratio determination

The determination of Poisson's ratio for each of the three materials, as a function of temperature, was made with "AVRO" high temperature ceramic strain gauges positioned to measure longitudinal and lateral strain on the tensile test specimens. Two gauges in each strain direction mounted on opposite faces of the specimen were averaged to eliminate bending effects. Each gauge had a combined thermocouple and of the four thermocouples one was used for temperature measurement, another was used for specimen temperature stabilisation, and the other two were used for temperature compensation of the measured strains.

3.2. Room temperature tensile tests

The room temperature porous specimens were of standard dimensions, 8" x $1\frac{1}{2}$" and were cut with orientations 0^{o} by 15^{o} to 90^{o} to the line of the warp. Tensile tests were carried out on a Denison testing machine using a Lindley extensometer for strain measurement.

3.3. Accuracy of test rigs

The heating equipment is capable of bringing a specimen up to temperature in less than 30 seconds, with soakage times of 1, 5, 10 and 30 minutes. A typical strain rate is to 0.1% proof in 10 secs. and to failure within 30 seconds. It is assumed that this rate of loading is sufficient to eliminate creep effects, yet not introduce dynamic effects. The temperature control holds the selected temperature to within approximately 3°C. The design accuracy of the extensometer was 50 micro-inches with a response time of less than ½ second. Full scale deflection response time of the function plotter is 2 seconds. Achieved accuracy is 0.05% for 0.1" extension and approximately 0.8% up to 0.1% proof extension. The strain gauges used for the determination of Poisson's ratio had a cross-sensitivity of less than 1%, and the Lindley extensometer was capable of measuring extensions of 1/20,000 inch on a 2" gauge length.

4. Results

The values of Young's modulus, secant modulus, proof stresses, and Poisson's ratio are presented for each material at various temperatures in Figs. 1-3 and Tables 1-3. The room temperature test results for the porous material for various orientations are given in Fig. 4 and Table 4.

5. Discussion of Elevated Temperature Results

5.1. D.T.D.166B

The elevated temperature tensile test results for D.T.D.166B are obtained after rapid heating, and short time soaking (approximately 10 minutes).

The only known reference to equivalent work on D.T.D.166B is given in Ref. 1 and the results are shown in Fig. 2 for the temperature range 0-400°C. The U.T.S. results show reasonable agreement apart from the low value obtained by the author at 350°C. The 0.1% proof results show closer agreement.

It is interesting to note that at 1000°C the % elongation was 25% ~~of the value at room temperature~~ suggesting that the material is then fully softened, and perhaps equivalent to D.T.D.171.

5.2. D.T.D.171

Tensile tests were performed after similar heating and soakage times to those for D.T.D.166B. A very close comparison exists between D.T.D.176 bar and D.T.D.171 sheet ultimate tensile strengths up to 600°C (Fig. 2). The D.T.D.176 bar properties are taken from Ref. 1. D.T.D.176 is an 18% Cr, 8% Ni austenitic stainless steel and is similar to F.V. F.M.B. and hence D.T.D.171 in composition and properties.

5.3. Rigimesh porous material

The specimens were subjected to a similar heating and soaking cycle as applied to D.T.D.166B. The material behaves in a similar manner to D.T.D.166B, the strength reducing from 20°C to 350°C followed by a slight recovery to 500°C and then a reduction to 1000°C. Since the material is non-homogeneous the quotient of lateral and longitudinal strains only gives an "effective" value of Poisson's ratio. The low values of Poisson's ratio obtained imply high values of the shear modulus G if $E = 2G(1 + \nu)$.

Very low values of % elongation were apparent, being in the range 2% to 3% over a two inch gauge length. Thus, severe deformation of the material is liable to promote premature failure.

5.4. Moduli

Values of Young's modulus and secant modulus (at 0.1% proof stress) are given for each material as a function of temperature in Fig. 1. For all materials the moduli tend to increase with initial rise in temperature, with maximum values in the range 200-350°C followed by a reduction to minimum values at 1000°C.

5.5. Porous material properties for various orientations

The warp of the woven material has 24 wires to the inch, while the weft has 110 to the inch, each having, supposedly, the same total cross-sectional area (manufacturers claim). The room temperature tensile tests carried out at various angles to the warp (0° to 90°) tended to disprove this (Fig. 4).

The ultimate tensile stress increased from a minimum for loading along the warp to a value almost twice this for loading along the weft. The value of E was a minimum at 45° with maximum values at 0° and 90°, while the % elongation showed the opposite variation.

6. Conclusions

The properties of D.T.D.166B and D.T.D.171 lay within specification property range at room temperature.

The porous material properties do not compare with those of the solid materials except at very high temperature. If specific strength and stiffness are considered, slightly more favourable comparisons result, since the density ratio of solid to porous material is approximately 1.15.

For uni-directional stress systems a very narrow angle warp-to-weft weave may be more efficient structurally yet still retain its porosity.

It must be emphasised that the results presented have been obtained from single specimens. Because of this they must be considered only as tentative and for more rigorous results a more comprehensive test programme would be necessary.

7. References

1. Meikle, G., Bunning, M.S. — The effect of heating steels to moderately elevated temperatures. R.A.E. TN. Met.199, 1959.

TABLE 1

MATERIAL PROPERTIES AT ELEVATED TEMPERATURES

D.T.D.166B

D.T.D.166B STAINLESS STEEL						
Tons/Square Inch						
Temp. °C	U.T.S.	0.1% Proof	0.2% Proof	0.3% Proof	E	E_s (0.1% Proof)
20	60.9	49.6	52.3	53.5	10,300	8400
350	40.4	34.5	36	36.6	11,050	8610
500	45.9	44.3	45	45.8	9,370	7770
1000	3.69	2.16	2.3	2.56	956	818

TABLE 2

MATERIAL PROPERTIES AT ELEVATED TEMPERATURES

D.T.D.171

D.T.D.171 STAINLESS STEEL						
Tons/Square Inch						
Temp. °C	U.T.S.	0.1% Proof	0.2% Proof	0.3% Proof	E	E_s (0.1% Proof)
20	37.7	17.05	18.05	18.6	12500	7620
200	31.3	16.1	17.1	17.5	13900	7590
350	28.9	13.55	14.7	15.6	16600	6990
500	28.2	12.25	13.4	14.2	15900	6210
750	17.1	10.8	11.4	11.85	9120	5220
1000	4.31	3.1	3.39	3.57	4420	2065

TABLE 3

MATERIAL PROPERTIES AT ELEVATED TEMPERATURES

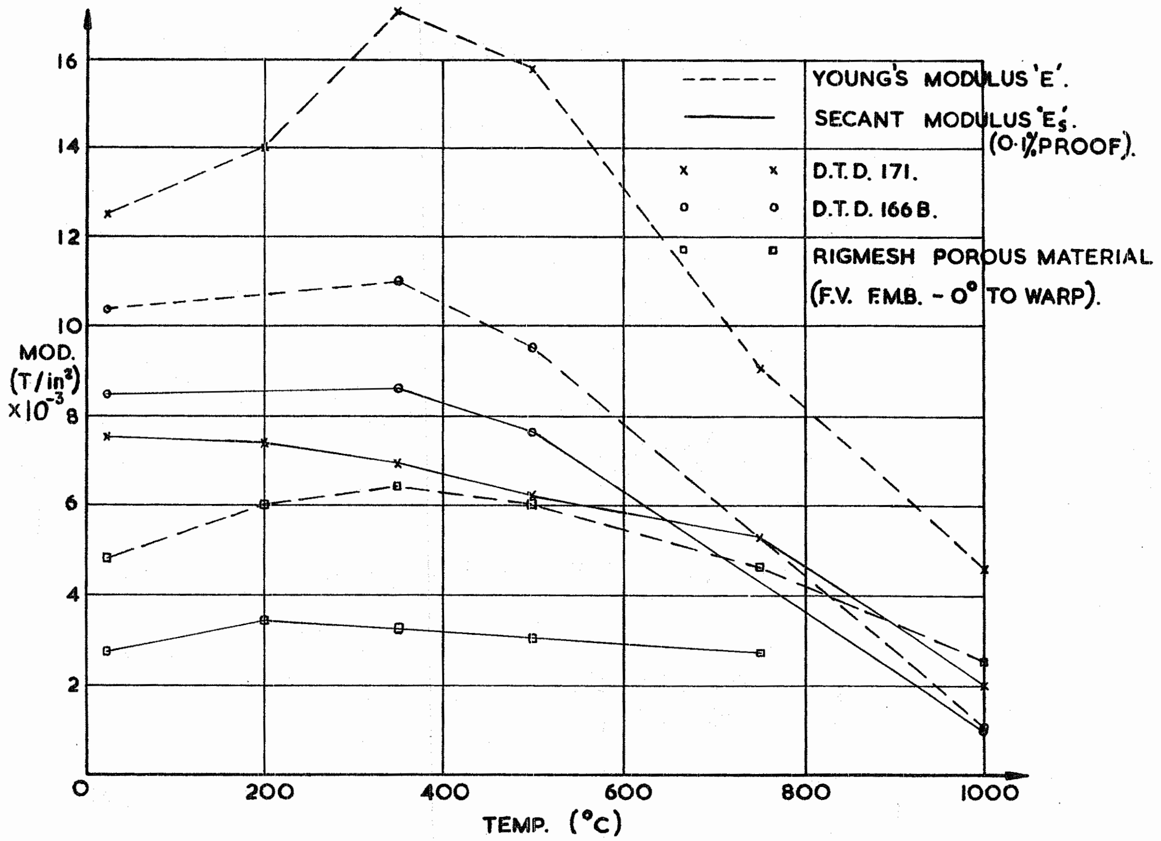
"RIGIMESH"

RIGIMESH POROUS WOVEN STAINLESS STEEL (30 Micron) (Firth Vickers F.M.B. Wire - Loading Applied in Direction of Warp)						
Temp. °C.	U.T.S.	0.1% Proof	0.2% Proof	0.3% Proof	E	E_s (0.1% Proof)
20	10.40	7.90	8.42	-	4760	2730
200	8.87	7.15	7.52	7.70	5960	3580
350	7.05	6.58	6.75	-	6440	3380
500	7.31	6.45	6.72	6.80	6050	3180
750	6.31	5.95	6.20	6.30	4500	2840
1000	2.84	-	-	-	2490	-

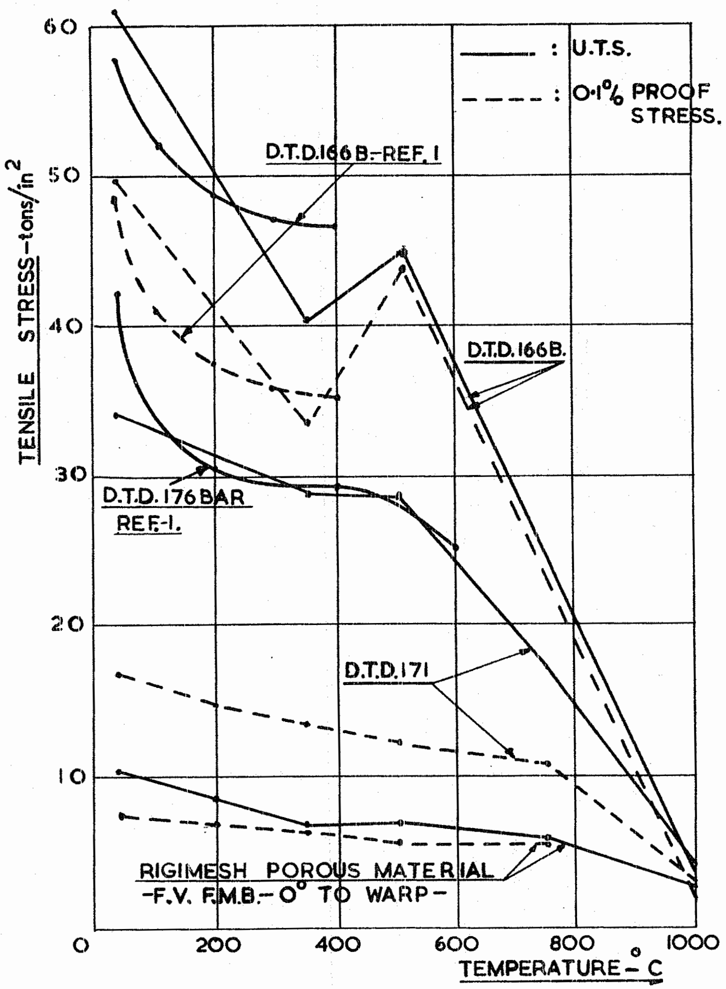
TABLE 4

POROUS SHEET METAL PROPERTIES AT ROOM TEMPERATURE

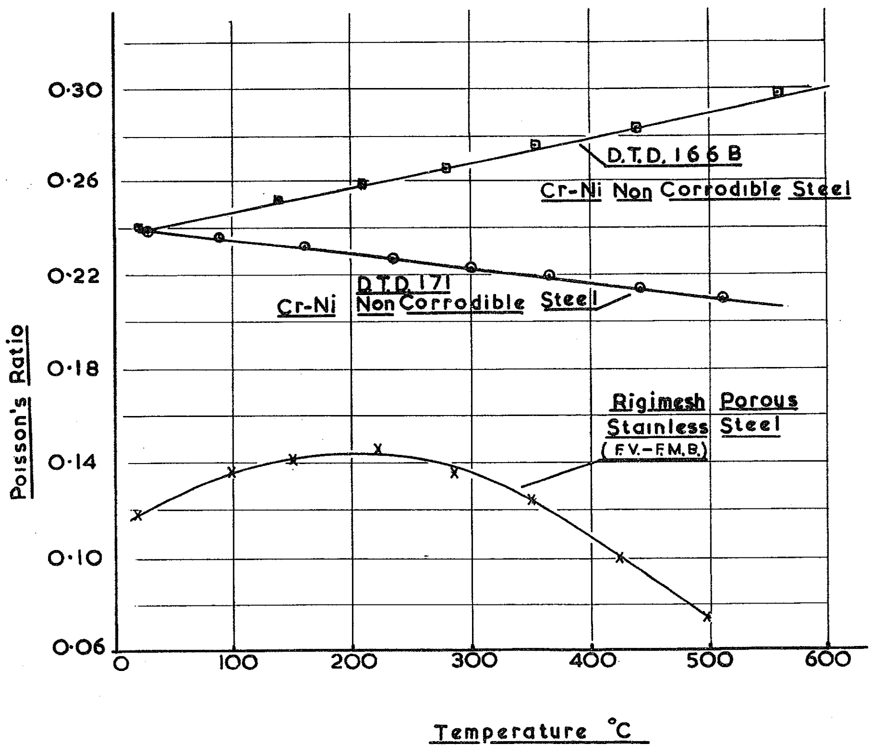
Porosint 'Rigimesh' Porous Woven Stainless Steel Sheet (30 Micron Porosity)							
	Direction of Loading Relative to the Warp (Degrees)						
Material Property	0	15	30	45	60	75	90
U.T.S. Tons/in^2	9.90	10.15	10.45	12.05	13.19	14.60	18.05
0.1% Proof Tons/in^2	8.21	7.33	6.70	6.35	7.01	8.76	12.90
E Tons/in^2	4820	4150	3660	3315	3680	5890	6200
% Elongation 2" G.L.	2.0	4.5	14.0	15.0	15.0	6.5	5.0
Fractured Weave	Warp	Warp	Warp	Warp	Weft	Weft	Weft



MODULI AS A FUNCTION OF TEMPERATURE FOR VARIOUS MATERIALS. (≈20 S.W.G. SHEET.) FIG.1.



U.T.S. & 0·1% PROOF STRESS FOR VARIOUS MATERIALS: ≈20 SWG SHEET FIG.2



VARIATION OF POISSONS RATIO WITH TEMPERATURE

FOR STAINLESS STEEL SHEET. FIG.3

RIGIMESH POROUS MATERIAL PROPERTIES AT ROOM TEMPERATURE AND VARIOUS ANGLES TO THE WEAVE.

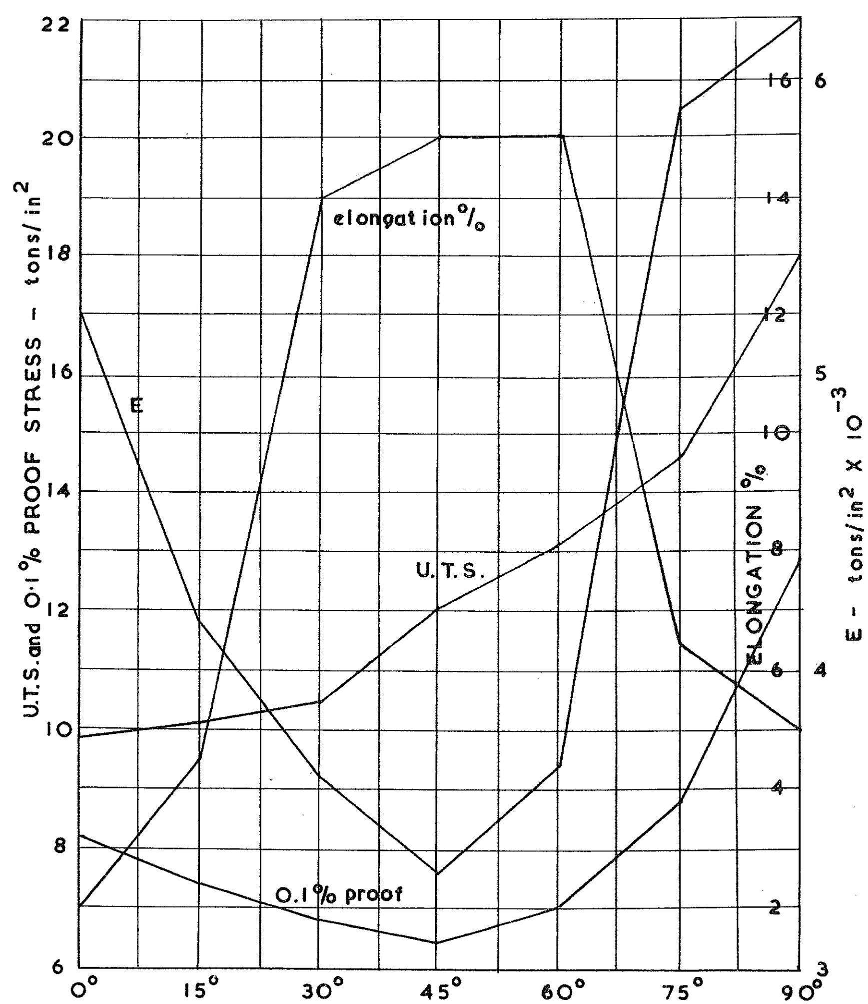


FIG.4