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by

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SOME MECHANICAL PROPERTIES OF DTD 5025 MAGNESIUM ALLOY CASTINGS

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SUMMARY

This Report describes an investigation into the tensile and torsional properties of DTD 5025 magnesium alloy castings. Strength and stiffness values are given, and the variation of these parameters between different batches and manufacturers is shown. The effect on mechanical properties of long and short term temperature environments is indicated.

* Replaces RAE Technical Report 70124 - ARC 32722

CONTENTS

1 INTRODUCTION

The mechanical properties of sand cast light alloys vary more than those of most other forms of metallic materials and it is therefore necessary, when evaluating them, to test a large number of specimens from different batches produced by different manufacturers. This Report describes an evaluation of four batches of DTD 5025 magnesium alloy castings, two produced by each of two manufacturers. Tensile and torsional properties are presented together with the effects on these of periods of heating, typical of environments which the castings might experience during service. Identical tests were carried out on specimens from each batch. At room temperature, the number of specimens was sufficient to provide information on batch-to-batch variations and variations between manufacturers; the elevated temperature tests were designed to give environmental effects only, and fewer specimens were thus utilised. Attention is concentrated in this investigation on tensile and torsional (shear) properties, since the scatter is likely to be greater in these than in compressive properties, where the effect of inclusions is usually less important.

The experimental programme is one proposed by the Metallic Materials Sub-Committee of the Joint Airworthiness Committee in 1960, and was one of a series of programmes, initiated by the Sub-Committee, to evaluate light alloy castings. Work prior to 1965 which included the majority of the tensile tests was carried out at the Metallurgy Department, Battersea College of Technology (now the University of Surrey) under a Ministry of Aviation contract. Mr. M. G. Bader of that department was responsible for that part of the programme. Subsequent work was done at Structures Department, R.A.E.

2 MATERIAL AND SPECIMEN PREPARATION

Two manufacturers, identified in this Report as A and B, each supplied two batches of magnesium alloy castings to specification DTD 5025, there being twenty-four castings in each batch. The chemical composition and mechanical properties in this specification are given in Tables 1 and 2 respectively.

The casting design used in this investigation was prepared under the auspices of the Metallic Materials Sub-Committee of the Joint Airworthiness Committee[1] for use as a standard in the evaluation of cast metallic materials and is shown in Figs.1 and 2. The design incorporates features typical of practical components and consists of a cylindrical barrel, together with an I section beam at right angles to the barrel.

The castings, which were heat treated at the founders, were ordered and released to an abbreviated A.I.D. procedure by Battersea College of Technology. Specimens found to be defective by radiological examination were rejected. However, subsequent machining of castings which appeared sound in this examination revealed a large number of inclusions, varying in length up to a few millimetres. These inclusions consisted of fragments of foreign material, sometimes associated with a void. Such inclusions and their effect on the experimental results will be discussed in section 4.5.

All tensile test pieces were extracted from the barrel of the casting, the axis of the specimen being parallel to the axis of the barrel, and were machined to the dimensions shown in Fig.3. It should be noted that tensile specimens to be loaded at elevated temperature are longer than those to be loaded at room temperature, the former being machined to allow for a 2 inch gauge length extensometer.

Torsional specimens were machined from the barrel of the casting, to the dimensions shown in Fig.4, care being taken to ensure that the bore was concentric with the outer surface and that the flanges were perpendicular to the axis of the specimen.

3 EXPERIMENTAL PROCEDURE

3.1 Environmental heating

Long term environmental heating was represented in the appropriate tests by periods of sustained heating at temperatures ranging from 120°C to 200°C for times varying from 200 hours to 20000 hours; the environmental heating conditions are specified in Table 3. Short term environments were represented by shorter periods of 30 seconds to 300 seconds duration at higher sustained temperatures in the range 150°C to 300°C; these environments are detailed in Table 4.

The prolonged heating periods of 200 hours or more were achieved in air-circulating ovens, the temperature being controlled to within ±2°C. The shorter periods of heating were applied to tensile specimens by passing a direct current at low voltage through the specimen, thermocouples being attached at three points equi-spaced along the gauge length. The temperature at each point was monitored, the temperature at the central point being controlled. In this way each point was maintained within ±2°C of the required temperature. The control system used a variable dc supply, operating in the millivolt range, adjusted so that the voltage was equal to that of a thermocouple at the required test temperature. A servo-potentiometer was used to compare this voltage with the output voltage of the central thermocouple; the difference between these voltages was amplified and used to control the current passing through the specimen and thence the temperature.

Tensile specimens which were tested at the long term environmental temperatures were also maintained at the correct temperature during loading by the direct current heating method described above, with the exception of those from castings supplied by manufacturer A which were subjected to long term environments A1 and A2. These were tested at Battersea College of Technology, where the specimens were heated by immersion in a bath of silicone oil whose temperature was controlled to within $\pm 1^{o}C$ of the desired test temperature. No torsional specimens were tested at elevated temperature although such specimens were tested subsequent to environmental heating.

3.2 Tensile tests

Of the results quoted in this Report, the room temperature tensile tests on material which had not been subjected to environmental heating and half of the room temperature tensile tests and a few of the elevated temperature tensile tests on material subjected to long term environmental heating were carried out at Battersea College of Technology.

3.2.1 Room temperature tests

Tensile specimens tested at R.A.E. were loaded at a constant strain rate of about 0.5 mm per minute in a Denison 15000 lb tensile test machine. The applied load was measured using a ring dynamometer, mounted in series with the specimen, giving an output voltage proportional to load. Extension was measured using a modified dial gauge extensometer fitted with a linear differential transformer in place of the dial gauge; this gave a dc output having a voltage proportional to the extension. The output voltages from the dynamometer and extensometer were fed directly to a high sensitivity x-y function plotter adjusted to give convenient load and extension scales to record extension up to 0.5% proof stress.

Tensile specimens tested at Battersea College of Technology, were loaded in an Avery 2500 lb hydraulic tensile test machine at nominally constant strain rate. Load-extension curves were recorded autographically as for tests conducted at R.A.E., a Mohr and Federhaff electronic extensometer being used instead of the modified dial gauge extensometer.

The 0.1%, 0.2% and 0.5% proof stresses together with the ultimate stress and Young's modulus were derived from the load-extension curve. The 0.1% proof stress is defined as that stress which would produce a permanent elongation of 0.1% if the stress were removed. The 0.2% and 0.5% proof stresses are defined similarly. Percentage elongation was measured by marking the specimen off in ¼ inch intervals before the test, and measuring after the test the increased distance between two points either side of the fracture which were originally 1 inch apart.

3.2.2 Elevated temperature tests

Of the tensile specimens, all those subjected to short term environments and half of those subjected to long term environments were subsequently tested at their environmental temperature. In the tests at R.A.E. at elevated temperature, the same type of extensometer was used as in the room temperature tests, the specimen being electrically isolated from the extensometer and test machine by insulating bushes. Since the specimens in the elevated temperature tests at Battersea College of Technology were immersed in an oil bath, the Mohr and Federhaff electronic extensometer could not be used. Extension was measured instead using a dial gauge extensometer, designed by Mr. M. G. Bader, in which the dial gauge was above the oil bath. Load-extension curves were drawn by hand, and the tensile properties derived.

3.3 Torsional tests

Torsional tests were carried out in a M.A.N. 1000 kg m torsional test machine. Torsional strain was measured using an optical torsiometer having a 4 inch gauge length. The telescope and scale were placed to give a 100 inch (2.54 m) optical lever. There was no autographic recording, and the applied torque was read directly from the dial of the test machine. All the torsional tests were conducted at room temperature.

The proof stress, ultimate stress and shear modulus were calculated from the graph of torque plotted against the difference in scale readings reflected by the mirrors fixed to either end of the torsiometer. Torsional strain was deduced from this difference in scale readings using the length of the optical lever and the ratio of the gauge length to the outer radius of the tube.

Torsional stress was calculated by the formula,

$$\tau_s = \frac{16\ T\ D_1}{\pi\ (D_1^4 - D_2^4)}\ ,$$

where τ_s is the torsional shear stress at the outer surface of the tube, T is the applied torque and D_1 and D_2 are the outside diameter and inside diameter respectively. The torsional proof stress is defined[2] as that stress which produces a permanent strain of 0.0005 radians; this is illustrated in Fig.5.

4 RESULTS

4.1 Experimental programme

Each batch consisted of twenty-four castings which were allocated to provide test specimens as indicated in Fig.6; of each batch, sixteen castings were used for tensile tests while seven were used for torsional tests. A single casting produced twelve tensile specimens or one torsional specimen. Of any set of twelve tensile specimens, four were loaded without environmental heating to determine the room temperature tensile properties, and thus the variations between batches and manufacturers. The remaining specimens were tested to provide data on the effects of the long and short term temperature environments. Room temperature tensile tests without prior heating were conducted on every casting which provided tensile specimens and the tensile properties achieved under each environmental condition were directly related to the initial room temperature properties of the same casting. Of the seven torsional specimens in a batch, three were loaded at room temperature without prior heating, while the remaining four were subjected to long term environmental heating conditions as indicated in Fig.6, and subsequently loaded at room temperature. It will be noted from Fig.6 that while specimens subjected to long term environments were subsequently tested at room temperature and at elevated temperature, those subjected to short term environments were tested at the environmental temperature only. This programme was carried out on each of the four batches.

4.2 Tensile tests

4.2.1 Tensile tests without environmental heating

The proof stresses, ultimate stresses and Young's moduli measured in the room temperature tensile tests are given in Tables 5 and 6; each value shown is the mean derived from four specimens taken from the same casting. A typical room temperature stress-strain curve is shown in Fig.7. Mean values of the measured properties for each batch and each manufacturer are shown in Table 7. The coefficients of variation for each manufacturer and the overall coefficient of variation are also shown in this table and have been derived using the formula:-

$$v = \frac{100}{\bar{x}}\sqrt{\frac{\sum(x - \bar{x})^2}{n}}$$

where $v \equiv$ coefficient of variation expressed as a percentage, x an individual test result $\bar{x} \equiv$ mean value of x, and $n \equiv$ the number of test results.

4.2.2 Tensile tests after environmental heating

The results of tensile tests on specimens which have been subjected to environmental heating are given in Table 8 for long term environments and in Table 9 for short term environments; each tabulated value is the mean derived from four specimens taken from the same casting. Typical stress-strain curves for various environmental conditions are shown in Fig.7.

Table 10 illustrates the effect of long term environments on the tensile properties both at room temperature and at the environmental temperature. In Table 10, the properties quoted for specimens subjected to long term environmental temperatures are the mean of all the corresponding results in Table 8, while the room temperature properties are the corresponding means from Tables 5 and 6. Table 11 has been prepared similarly to illustrate the effects of short term environments on the tensile properties; in this case, the relevant properties were derived from Tables 5, 6 and 9.

Table 12 summarises the results of Tables 10 and 11, and expresses the effects of environmental heating on the ultimate tensile stress and 0.1% proof stress as 'heat factors' and 'recovery heat factors'. For the ultimate tensile stress, these factors are defined as follows:-

$$\text{Heat Factor for Ultimate Tensile Stress} = \frac{\text{Ultimate tensile stress of heated material at the environmental temperature}}{\text{Ultimate tensile stress at room temperature prior to heating}}$$

$$\text{Recovery Heat Factor for Ultimate Tensile Stress} = \frac{\text{Ultimate tensile stress at room temperature after heating}}{\text{Ultimate tensile stress at room temperature prior to heating}} .$$

The factors for 0.1% proof stress are defined similarly.

The variation of long term environmental heat factors for the 0.1% proof stress and the ultimate tensile stress are illustrated in Figs.8 and 9 respectively, while Fig.10 shows the variation of Young's modulus with long term environmental temperature. Figs.11 to 13 show the corresponding variations for recovery properties. For short term environments, the variation of the heat factors for the 0.1% proof stress and ultimate stress with environmental temperature are shown in Fig.14, while the effect of environmental temperature on Young's modulus is shown in Fig.15.

4.3 Torsional tests

4.3.1 Torsional tests without environmental heating

Table 13 gives the torsional proof stresses, ultimate stresses and shear moduli derived from torsional tests on the unheated material. The mean values and coefficients of variation derived from Table 13 are shown in Table 14. A typical torsional stress-strain curve is presented in Fig.16.

4.3.2 Torsional tests after environmental heating

The results of the room temperature torsional tests after environmental heating are given in Table 15. The recovery heat factors derived from Tables 14 and 15 are given in Table 16. The variation of recovery heat factors and shear modulus with environmental temperature are shown graphically in Figs.17 and 18 respectively.

4.4 Comments on results

It should be noted that at several points in Tables 5, 6 and 8 results are not quoted, and, where possible, a reason for the absence of any particular value has been recorded. However, this Report describes an experimental programme conducted over a long period by a number of investigators, and not all the reasons for such omissions were recorded. In the case of castings P5 and P44, tensile specimens which had been subjected to long term environmental heating failed at an elongation of about 1%, (see Table 8) and therefore the 0.5% proof stress was not reached before ultimate failure of the specimen. Other tensile specimens, which were to be tested at elevated temperature, overheated in the area of an inclusion (see section 4.5) and therefore the results have been omitted. Apart from the overall shortage of values of elongation percentage at elevated temperature, the majority of missing values in Table 8 occur for specimens extracted from material supplied by manufacturer B, which was also found to contain a larger number of inclusions. The distribution and effects of such inclusions are discussed in detail in section 4.5.

Because of the scatter in material properties, in some cases the experimental evidence justifies only tentative conclusions about the effects of environmental heating as, for example, in Fig.10 which illustrates the values of Young's modulus measured at the various environmental temperatures; in this case it was not possible to draw a curve which was consistent with all the experimental evidence. In Figs.14, 15 and 18 curves have been drawn as chain lines because of the small number of test results. Individual experimental results have been recorded in all figures, and in deriving the curves it has been assumed that the properties of the casting are not greatly affected by small temperature changes in the region of room temperature.

4.5 Inclusions

It has already been noted in section 2 that the castings contained inclusions, which were revealed during the machining of test specimens. Such inclusions were also observed on the fracture surfaces of tensile and torsional specimens from all batches; two such inclusions, which were revealed on tensile fracture surfaces are illustrated in Fig.19. Inclusions varied in length up to about 5 mm and were generally in the form of flakes of foreign material, such as magnesium oxide or magnesium silicate, sometimes associated with a void of smaller size; these compounds are known to occur if insufficient precautions are taken when preparing magnesium sand castings. In general, in material supplied by manufacturer B, the inclusions were both larger and more numerous than in material supplied by manufacturer A; batch 2 supplied by manufacturer B was observed to be inferior in both these respects.

Inclusions are likely to give rise to the early onset of plastic flow in the surrounding material and cause an effective decrease in cross-sectional area if they are unable to carry load. However, inclusions such as those observed in this programme would be capable of sustaining some load and thus the effective reduction in area would be less than the cross-sectional area of the inclusions. Typical inclusions in this material varied considerably in size as stated above but occupied of the order of 10% of the cross-sectional area.

The values of Young's modulus and shear modulus were based on the appropriate gauge lengths, and any localised effects of inclusions would thus not greatly affect the results; any variations caused by inclusions would therefore probably be masked by scatter due to other causes which is generally associated with sand cast light alloy materials. Such scatter will be discussed further in section 5.1. The tensile and torsional proof stresses were also based on the appropriate gauge lengths and therefore localised variations in strain would again give rise to smaller variations in overall strain; such variations in overall strain correspond to very small variations in stress because of the low tangent modulus observed after the onset of plastic flow. As a result any effect on the tensile and torsional proof stress, caused by inclusions, would also be masked by the normal scatter of the material.

Ultimate failure of a tensile or torsional specimen will occur when the plastic strain at any point reaches its maximum value. Thus if the specimen contains an inclusion, failure will occur in the area of high localised strain surrounding the inclusion, before the overall strain has reached the expected failing strain. As a result the measured percentage elongation will be lower than that of a specimen containing no inclusions. However the ultimate stress will not be greatly affected because of the low tangent modulus, as mentioned above.

Such a reduction in percentage elongation, will be evident, for example, from the comparatively low values of elongation quoted for batch 2 from manufacturer B in Table 6. As mentioned in section 4.4 this batch contained the greatest number of large inclusions. Compared with the overall average elongation of 6.26% quoted in Table 7 the mean elongation of specimens having visible inclusions on their fracture surfaces was found to be 2.5%.

The presence of inclusions also affected the observed properties in tensile tests conducted at elevated temperature. (This will be discussed further in section 5.2.). In such tests the specimens were heated by passing a constant direct current, and an inclusion would cause a local increase in resistance which would cause a proportional rise in temperature. Such overheating would go unobserved unless it occurred near a thermocouple, or unless it was sufficient to cause a colour change at the surface of the specimen. Where the effect was observed the results of the tests have been omitted (cf. section 4.4). Where the effect was unobserved the applied environmental temperature might have been too high locally in the specimen, but in a manner which could not be controlled. This would have caused a larger scatter in the value of any mechanical property which is sensitive to this effect, while the derived mean for such properties would be typical of a slightly higher environmental temperature. It may be noted that this effect was observed, in specimens from castings P14, P58 and P80 which gave the lowest elongations at room temperature (see Table 6).

5 DISCUSSION

5.1 Room temperature properties

The results given for tensile and torsional properties in the summary Tables 7 and 14 show that the differences in mean strength and stiffness properties between batches supplied by a single manufacturer were small, being less than 6.1%. However the differences in mean properties between castings supplied by different manufacturers were significantly greater, being, for example, 8% between the 0.1% tensile proof stresses and 11% between the ultimate torsional stresses. It should be noted that the 0.1% tensile proof stresses for both batches supplied by manufacturer A were found to be below the minimum value quoted in the specification (see Table 2). However, it is generally accepted[3], that the mechanical properties of light alloy castings may differ unfavourably from the value quoted for a test bar in casting specifications, since specification values are based on specimens extracted from cast test bars of an idealised section; methods of strength approval for aircraft castings, which will usually be of differing geometry, make allowance for this possibility.

The scatter in the mechanical properties of cast materials is due primarily to the random size and orientation of the crystal grains which result from the way in which the melt flows into the mould and solidifies; extrusion and rolling processes which are employed in the production of other forms of metallic material tend to introduce some degree of grain orientation and uniformity of grain size. It is mainly for this reason that the scatter in properties of sand cast light alloy materials is generally higher than that of wrought metallic materials. The coefficients of variation of the 0.1% proof and ultimate tensile strengths of sand cast magnesium alloys generally lie within the range 7% to 21% [4,5]. It will thus be noted from Table 7 that, in spite of the presence of a large number of inclusions in the material, the overall coefficients of variation for the 0.1% proof and ultimate tensile strengths of the castings tested lie at the lower end of this range.

It is of interest to compare the material supplied by manufacturers A and B. Table 14 indicates that the mean values of torsional proof stress, ultimate stress and shear modulus of unheated specimens, were greater by 15%, 12% and 2% respectively, in B's material, while the coefficients of variation were very low, being 3.89% and 1.99% for the torsional proof and ultimate stresses and 2.59% for the shear modulus. From Table 7 it may be seen that while the 0.1%, 0.2% and 0.5% tensile proof stresses were more than 6% greater for material from manufacturer B, the ultimate tensile stress and Young's modulus were 2.5% and 1.5% lower, and the percentage elongation was 38% lower. As discussed in section 4.5 this large difference in percentage elongation appears to be due to the larger number of inclusions in B's material.

It may also be seen from Table 7 that the coefficients of variation for the 0.2% tensile proof stress and ultimate tensile stress for material from any single batch were greatest for batch 1 of A's material, being 7.67% and 10.85% respectively; the corresponding overall values for specimens from all batches were 7.05% and 9.52%.

5.2 Effects of environmental heating

Only specimens subjected to long term environmental heating were subsequently tested at room temperature. It may be seen from Figs.11, 12, 13, 17 and 18 that all the room temperature properties, apart from shear modulus, were virtually unaffected by the applied long term environments up to a temperature of about 150°C; only shear modulus, 0.1% proof and ultimate tensile stresses were significantly affected by temperatures between 150°C and 200°C. For example the shear modulus had fallen to about 85% of its original value after heating at 170°C and the 0.1% proof and ultimate tensile stresses had fallen to about 90% of their original values after 1000 hours at 200°C. Figs.11 and 12 also show that the time for which a specimen is subjected to a given environmental temperature has considerable effect on the 0.1% proof and ultimate tensile strengths at room temperature. For example, at 200°C the 0.1% proof stress fell to 88% of its original value after 1000 hours, compared to 97% after only 200 hours.

At both long and short term environmental temperatures, the heat effect was determined more by the test temperature than by the length of time for which the material had been subjected to that temperature. This may be seen for long term environments in Figs.8, 9 and 10 for short term environments in Figs.14 and 15; at 120°C the 0.1% proof stress, ultimate strength and Young's modulus had fallen to about 88%, 76% and 96% respectively of their room temperature values. At environmental temperatures above 120°C, the 0.1% proof and ultimate stresses continue to fall to about 65% and 55% respectively at 200°C. At short term environmental temperatures between 200°C and 300°C the fall in tensile properties become more pronounced, so that at 300°C, the Young's modulus was 70% of its original value while the 0.1% proof and ultimate strengths were only 40% of their room temperature values.

The results of tests conducted at elevated temperature show higher scatter in properties than the results of room temperature tests (see also section 4.4); this was particularly noticeable at the higher environmental temperatures. For example, the values observed at short term environments B3 and B4 in Table 9 vary by up to 100%. Because of this scatter, and the limited number of specimens subjected to each environmental condition, only a general indication of the effect of elevated temperature environments on the mechanical properties may be deduced.

6 CONCLUSIONS

This Report has described an exercise to evaluate the mechanical properties of magnesium alloy sand castings to specification DTD 5025, and to determine the effect of both long and short term elevated temperature environments on such properties. Tests were carried out on four batches of castings, supplied by two different manufacturers (designated A and B). Considerable numbers of inclusions were observed, these first being revealed during specimen machining, and subsequently being observed on the fracture surfaces. Manufacturer B's material exhibited advantageous room temperature mechanical properties. Nevertheless it is unlikely that material such as that supplied by manufacturer B would be accepted for class I castings in aircraft applications, since the defects would be detected in the standard approval procedure by break-up tests or by more extensive radiological examination.

The application of long term environmental heating periods in general caused reductions in the room temperature mechanical properties, although such reductions were in many cases only slight for environmental temperatures below 120°C. For higher environmental temperatures the effects were more pronounced, for example a 10% reduction occurred in the 0.1% tensile proof stress after 1000 hours at 200°C and a 15% reduction occurred in the shear modulus after heating at 200°C for either 200 hours or 1000 hours.

At all environmental temperatures, the reduction in mechanical properties was greater, being affected more by the test temperature than by the time for which the material had been subjected to that temperature; for example, the ultimate tensile strength was reduced to about 55% of its toom temperature value at 200°C for both long and short term environmental heating periods, and to about 40% of its room temperature value at 300°C for the short term environmental heating period.

Acknowledgments

Acknowledgment is due to Mr. M. G. Bader, Department of Metallurgy and Materials Technology, University of Surrey, who was responsible for the execution of the programme from its initiation until 1965. Acknowledgment is also due to the late Mr. D. F. Wright, of Structures Department, R.A.E., who was primarily responsible from 1965 until 1969 for the execution of this programme.

Table 1

CHEMICAL COMPOSITION OF CASTINGS - FROM SPECIFICATION DTD 5025

Element	Per cent	
	Min	Max
Silver	2.0	3.0
Total rare earth metals	1.2	2.0
Zirconium 'available'	0.1	1.0
Zinc		0.2
Manganese		0.15
Copper		0.03
Silicon		0.01
Iron		0.01
Nickel		0.005
Magnesium		the remainder

Table 2

MINIMUM MECHANICAL PROPERTIES OF TEST BARS - FROM SPECIFICATION DTD 5025

0.1% proof stress	Tensile strength	Elongation percentage
10.0 tonf in^{-2} (154.4 MN m^{-2})	15.5 tonf in^{-2} (239.4 MN m^{-2})	4%

Table 3

LONG TERM ENVIRONMENTAL HEATING CONDITIONS

Reference number	Temperature °C	Time h
A1	120	200
A2	120	1000
A3	120	10000
A4	120	20000
A5	150	200
A6	150	1000
A7	150	10000
A8	150	20000
A9	170	200
A10	170	1000
A11	200	200
A12	200	1000

Table 4

SHORT TERM ENVIRONMENTAL HEATING CONDITIONS

Reference number	Temperature °C	Time s
B1	150	30
B2	200	30
B3	250	30
B4	300	30
B5	200	300

Table 5A

ROOM TEMPERATURE TENSION TESTS - MANUFACTURER A (S.I. UNITS)

	Casting	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
	6100	132.7	148.9	177.6	249.9	45.8	6.3
	6495	164.5	180.7	217.3	274.9	48.1	8 9
	6496	162.0	177.6	207.0	253.0	47.4	6.8
	6497	162.1	171.4	205.4	257.9	46.7	4.3
	6678	150.3	162.5	201.9	227.2	44.5	5.7
	6503	160.2	176.2	203.7	256.4	45.9	8.0
	6681	144.7	168.7	190.3	252.1	45.0	9.3
Batch 1	6103	144.4	157.5	185.3	264.1	45.5	9.5
	6104	149.0	162.9	190.7	257.8	47.5	10.1
	6106	150.0	164.6	192.3	240.3	50.2	6.5
	6498	143.8	158.3	185.8	206.6	39.6	4.3
	6501	166.2	182.7	215.1	265.0	49.6	6.3
	6684	153.8	167.4	196.6	248.7	47.6	5.0
	6108	144.1	158.3	184.4	234.6	45.1	5.5
	6502	164.9	180.7	178.5	268.0	43.9	9.8
	6685	151.5	164.0	191.4	243.9	48.5	6.5
	6250	151.8	167.4	193.8	266.0	46.4	8.5
	6255	158.5	173.0	196.1	274.9	48.6	13.3
	6258	156.0	167.0	194.6	264.4	46.9	5.4
	6260	155.4	171.1	197.7	271.8	47.3	10.8
	7025	155.2	167.4	194.4	269.2	46.8	9.4
	7028	150.9	165.4	193.1	267.6	47.2	8.9
	7029	144.7	160.3	187.2	260.5	45.2	11.1
Batch 2	6110	138.4	152.6	182.9	259.9	46.2	12.3
	6112	137.0	150.1	177.6	253.4	50.0	10.0
	6257	148.3	160.0	185.0	250.5	43.2	6.0
	6262	149.3	163.9	- *	220.9	49.0	5.3
	7031	145.9	160.5	189.2	244.0	47.2	6.0
	7033	147.5	160.2	187.6	249.4	44.7	6.4
	6263	160.0	173.9	200.3	265.0	44.9	6.5
	7034	144.6	162.8	190.9	261.0	43.9	6.8
	7035	152.4	167.3	194.4	232.9	48.1	7.0

* Not measured

Table 5B

ROOM TEMPERATURE TENSION TESTS - MANUFACTURER A (IMPERIAL UNITS)

	Casting	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus $\times 10^6$ lbf in^{-2}	Percentage elongation %
Batch 1	6100	8.59	9.64	11.50	16.18	6.64	5.3
	6495	10.65	11.70	14.07	17.80	6.98	8.9
	6496	10.49	11.50	13.40	16.38	6.88	6.8
	6497	10.50	11.10	13.30	16.70	6.78	4.3
	6678	9.73	10.52	13.07	14.71	6.46	5.7
	6503	10.37	11.41	13.19	16.60	6.65	8.0
	6681	9.37	10.92	12.32	16.32	6.52	9.3
	6103	9.35	10.20	12.00	17.10	6.60	9.5
	6104	9.65	10.55	12.35	16.69	6.89	10.1
	6106	9.71	10.66	12.45	15.56	7.28	6.5
	6498	9.31	10.25	12.08	13.38	5.75	4.3
	6501	10.76	11.83	13.93	17.16	7.20	5.3
	6684	9.96	10.84	12.73	16.10	6.90	5.0
	6108	9.33	10.25	11.94	15.19	6.54	5.5
	6502	10.68	11.70	11.56	17.35	6.36	9.8
	6685	9.81	10 62	12.39	15.79	7.03	6.5
Batch 2	6250	9.83	10.84	12.55	17.22	6.73	8.5
	6255	10.26	11.20	12.70	17.80	7.05	13.3
	6258	10.10	10.81	12.60	17.12	6.80	5.4
	6260	10.06	11.08	12.80	17.60	6.86	10.8
	7025	10.05	10.84	12.59	17.43	6.79	9.4
	7028	9.77	10.71	12.50	17.33	6.85	8.9
	7029	9.37	10.38	12.12	16.87	6.56	11.1
	6110	8.96	9.88	11.84	16.83	6.70	12.3
	6112	8.87	9.72	11.50	16.43	7.25	10.0
	6257	9.60	10.36	11.98	16.22	6.26	6.0
	6262	9.67	10.61	- *	14.30	7.11	5.3
	7031	9.45	10.39	12.25	15.80	6.85	6.0
	7033	9.55	10.37	12.15	16.15	6.49	6.4
	6263	10.36	11.26	12.97	17.16	6.51	6.5
	7034	9.60	10.54	12.36	16.90	6.36	6.8
	7035	9.87	10.83	12.59	15.08	6.98	7.0

* Not measured

Table 6A

ROOM TEMPERATURE TENSION TESTS - MANUFACTURER B (S.I. UNITS)

	Casting	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
	P4	176.5	191.5	217.8	264.9	45.0	5.9
	P1	170.7	177.1	207.6	260.4	45.6	5.9
	P5	170.5	185.3	211.9	266.9	45.4	6.0
	P11	167.3	191.4	208.5	241.7	44.0	3.5
	P14	166.0	180.1	207.0	241.1	44.0	2.3
	P26	164.6	178.5	204.3	250.8	44.5	4.7
	P36	161.4	175.7	200.2	259.0	45.0	7.4
Batch 1	P50	163.4	175.1	201.9	260.4	44.8	5.7
	P53	-	NO RESULTS AVAILABLE		-	-	-
	P9	159.8	176.2	211.4	265.0	48.7	6.3
	P16	165.1	177.9	206.6	252.5	43.7	6.0
	P29	166.0	179.6	206.6	245.1	44.9	3.4
	P37	165.1	180.1	206.8	248.7	44.3	2.8
	P17	163.7	178.7	202.6	246.2	47.4	6.8
	P30	166.2	180.7	209.3	249.3	46.7	5.8
	P38	164.8	178.8	207.3	247.6	48.1	4.3
	P34	165.4	183.2	208.3	255.0	45.2	5.4
	P20	158.3	176.1	192.1	238.9	47.6	3.2
	P44	161.1	176.1	201.1	247.4	45.0	5.9
	P51	163.1	180.4	204.6	263.5	45.4	7.3
	P58	162.0	179.0	205.9	240.3	46.1	1.3
	P65	167.7	183.8	210.5	239.5	43.8	3.6
	P68	163.6	174.8	205.4	215.0	44.3	5.8
Batch 2	P75	163.9	177.6	204.5	247.6	44.5	3.9
	P80	169.4	182.9	211.3	237.8	44.8	2.2
	P24	162.3	177.9	207.9	256.5	46.7	7.0
	P47	158.6	173.3	200.9	242.6	45.2	2.9
	P66	163.6	178.1	206.6	251.9	45.3	6.5
	P72	165.1	181.8	210.4	249.4	47.2	2.7
	P67	162.2	176.4	206.6	228.1	50.9	3.5
	P73	164.5	178.4	202.2	229.3	48.2	5.5
	P78	162.0	175.1	204.3	219.0	47.2	4.5

Table 6B

ROOM TEMPERATURE TENSION TESTS - MANUFACTURER B (IMPERIAL UNITS)

	Casting	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus × 10^{-6} lbf in^{-2}	Percentage elongation %
	P4	11.43	12.40	14.10	17.15	6.52	5.9
	P1	11.05	11.47	13.44	16.86	6.62	5.9
	P5	11.04	12.00	13.72	17.28	6.58	6.0
	P11	10.83	12.39	13.50	15.65	6.38	3.5
	P14	10.75	11.66	13.40	15.61	6.38	2.3
	P26	10.66	11.56	13.23	16.24	6.45	4.7
	P36	10.45	11.38	12.96	16.77	6 53	7.4
Batch 1	P50	10.58	11.34	13.07	16.86	6.50	5.7
	P53	-	-	NO RESULTS AVAILABLE		-	-
	P9	10.35	11.41	13.69	17.16	7.06	6.3
	P16	10.69	11.52	13.38	16.35	6.34	6.0
	P29	10.75	11.63	13.38	15.87	6.51	3.4
	P37	10.69	11.66	13.39	16.10	6.43	2.8
	P17	10.60	11.57	13.12	15.94	6.87	6.8
	P30	10.76	11.70	13.55	16.14	6.77	5.8
	P38	10.67	11.58	13.42	16.03	6.98	4.3
	P34	10.71	11.86	13.49	16.51	6.56	5.4
	P20	10.25	11.40	12.44	15.47	6.90	3.2
	P44	10.43	11.40	13.02	16.02	6.53	5.9
	P51	10.56	11.68	13.25	17.06	6.58	7.3
	P58	10.49	11.59	13.33	15.56	6.68	1.3
	P65	10.86	11.90	13.63	15.51	6.35	3.6
	P68	10 59	11.32	13.30	13.92	6.43	5.8
Batch 2	P75	10.61	11.50	13.24	16.03	6.45	3.9
	P80	10.97	11.84	13.68	15.40	6.50	2.2
	P24	10.51	11.52	13.46	16.61	6.78	7.0
	P47	10.27	11.22	13.01	15.71	6.56	2.9
	P66	10.59	11.53	13.38	16.31	6.57	6.5
	P72	10.69	11.77	13.62	16.15	6.85	2.7
	P67	10.50	11.42	13.38	14.77	7.38	3.5
	P73	10.65	11.55	13.09	14.85	6.99	5.5
	P78	10.49	11.34	13.23	14.18	6.85	4.5

Table 7A

MEAN VALUES AND COEFFICIENTS OF VARIATION OF TENSILE PROPERTIES (S.I. UNITS)

Number of specimens on which value is based	Manufacturer	Batch	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
64	A	1	152.7	167.7	195.2	250.0	46.3	7.05
64	A	2	150.0	163.9	191.0	257.0	46.6	8.36
128	A	1 + 2	151.4	165.7	193.2	253.5	46.5	7.70
60	B	1	166.0	180.4	207.3	253.3	45.4	5.12
64	B	2	163.2	178.4	203.2	241.4	46.1	4.45
124	B	1 + 2	164.6	179.5	205.3	247.1	45.8	4.77
252	Mean values all batches		157.8	172.5	199.2	250.4	46.1	6.26

	Coefficients of variation (%) Manufacturer	Batch	0.1% proof stress	0.2% proof stress	0.5% proof stress	Ultimate stress	Young's modulus	Percentage elongation
64	A	1	8.54	7.67	6.63	10.85	9.80	49.70
64	A	2	5.26	4.78	3.65	6.52	5.21	36.87
128	A	1 + 2	7.09	6.39	5.42	9.03	7.89	43.83
60	B	1	4.72	4.47	3.22	8.66	4.49	55.28
64	B	2	3.81	4.17	4.01	10.41	6.19	62.90
124	B	1 + 2	4.36	4.41	3.70	9.81	5.45	59.35
252	All batches		7.66	7.05	5.89	9.52	6.96	55.40

Table 7B

MEAN VALUES OF TENSILE PROPERTIES (IMPERIAL UNITS)

Manufacturer	Batch	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus 10^{-6} lbf in^{-2}
A	1	9.89	10.86	12.64	16.19	6.72
A	2	9.71	10.61	12.37	16.64	6.76
A	1 + 2	9.80	10.73	12.51	16.41	6.74
B	1	10.75	11.68	13.42	16.40	6.59
B	2	10.57	11.55	13.16	15.63	6.69
B	1 + 2	10.66	11.62	13.29	16.00	6.64
Mean values all batches based on 252 specimens		10.22	11.17	12.90	16.21	6.69

Table 8A

LONG TERM ENVIRONMENTAL TENSILE TESTS (S.I. UNITS)

Casting	Environmental condition	Test condition	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
6495	A1	ET ≠	152.7	162.9	172.7	212.8	35.8	31.9
6255	A1	ET ≠	146.1	154.9	167.4	208.5	34.3	30.8
P1	A1	ET ≠	140.7	149.7	157.2	169.1	41.5	-
P20	A1	ET ≠	147.5	159.2	170.2	184.9	42.7	-
6495	A1	RT ≠	163.4	181.2	209.3	277.7	47.1	14.18
6255	A1	RT ≠	158.8	173.7	200.0	278.0	46.3	6.95
P1	A1	RT ≠	167.9	178.5	205.9	264.1	49.0	4.88
P20	A1	RT ≠	168.3	183.2	210.0	268.4	46.9	4.78
6496	A2	ET	153.4	162.6	176.1	211.6	41.6	22.0
6258	A2	ET	139.2	149.2	160.6	194.3	38.4	21.4
P5	A2	ET	146.6	154.8	161.4	175.1	41.2	-
P44	A2	ET	134.4	144.1	146.1	154.9	42.9	-
6496	A2	RT	169.1	183.8	210.8	257.1	44.7	14.3
6258	A2	RT	157.2	171.4	196.9	271.8	42.3	13.7
P5	A2	RT	171.0	187.3	- *	254.6	46.3	0.95
P44	A2	RT	166.0	180.5	- *	231.0	47.2	1.05
6497	A3	ET	150.1	157.8	173.6	195.8	43.0	-
6260	A3	ET	137.6	146.3	154.8	183.9	43.7	-
P11	A3	ET	-	NO RESULTS AVAILABLE		-	-	-
P51	A3	ET	150.1	160.0	171.1	185.5	47.0	-
6497	A3	RT	165.9	178.2	204.6	261.5	47.4	9.3
6260	A3	RT	156.5	171.9	199.7	267.6	46.9	9.7
P11	A3	RT	163.7	177.0	195.1	232.4	46.6	1.8
P51	A3	RT	166.8	181.5	208.5	219.3	50.3	1.4
6678	A4	ET	136.4	146.6	154.4	179.0	41 7	-
7025	A4	ET	141.3	150.4	159.8	185.9	41.0	-
P14	A4	ET	-	SPECIMENS OVERHEATED AT INCLUSIONS				-
P58	A4	ET						
6678	A4	RT	158.5	173.3	201.2	245.7	44.2	5.7
7025	A4	RT	152.1	164.3	191.2	259.8	44.5	6.8
P14	A4	RT	170.8	185.5	206.0	248.7	46 1	3.0
P58	A4	RT	167.7	180.7	206.6	241.1	45.4	7.5

≠ ET = Elevated Temperature
RT = Room Temperature
* Not achieved due to low elongation

Table 8B

LONG TERM ENVIRONMENTAL TENSILE TESTS (IMPERIAL UNITS)

Casting	Environmental condition	Test condition	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus × 10^{-6} lbf in^{-2}	Percentage elongation %
6495	A1	ET	9.89	10.55	11.18	13.78	5.19	31.9
6255	A1	ET	9.46	10.03	10.84	13.50	4.97	30.8
P1	A1	ET	9.11	9.69	10.18	10.95	6.02	-
P20	A1	ET	9.55	10.31	11.02	11.97	6.20	-
6495	A1	RT	10.85	11.73	13.55	17.98	6.83	14.18
6255	A1	RT	10.28	11.25	12.95	18.00	6.71	6.75
P1	A1	RT	10.87	11.56	13.33	17.10	7.10	4.88
P20	A1	RT	10.90	11.86	13.60	17.38	6.80	4.78
6496	A2	ET	9.93	10.53	11.40	13.70	6.04	22.0
6258	A2	ET	9.01	9.66	10.40	12.58	5.57	21.4
P5	A2	ET	9.49	10.02	10.45	11.34	5.98	-
P44	A2	ET	8.70	9.33	9.46	10.03	6.22	-
6496	A2	RT	10.95	11.90	13.65	16.65	6.48	14.3
6258	A2	RT	10.18	11.10	12.75	17.60	6.14	13.7
P5	A2	RT	11.07	12.13	- *	16.81	6.72	0.95
P44	A2	RT	10.75	11.69	- *	14.96	6.84	1.05
6497	A3	ET	9.72	10.22	11.24	12.68	6.23	-
6260	A3	ET	8.91	9.47	10.02	11.91	6.34	-
P11	A3	ET	-	NO RESULTS AVAILABLE		-	-	-
P51	A3	ET	9.72	10.36	11.08	12.01	6.81	-
6497	A3	RT	10.74	11.54	13.25	16.93	6.88	9.3
6260	A3	RT	10.13	11.13	12.93	17.33	6.80	9.7
P11	A3	RT	10.60	11.46	12.63	15.05	6.76	1.8
P51	A3	RT	10.80	11.75	13.50	14.20	7.30	1.4
6678	A4	ET	8.83	9.49	10.00	11.57	6.05	-
7025	A4	ET	9.15	9.74	10.35	12.04	5.95	-
P14, P58	A4	ET	-	SPECIMENS OVERHEATED AT INCLUSIONS				-
6678	A4	RT	10.26	11.22	13.03	15.91	6.41	5.7
7025	A4	RT	9.85	10.64	12.38	16.82	6.45	6.8
P14	A4	RT	11.06	12.01	13.34	16.10	6.68	3.0
P58	A4	RT	10.86	11.70	13.38	15.61	6.59	7.5

* Not achieved due to low elongation

Table 8A (Cont'd)

LONG TERM ENVIRONMENTAL TENSILE TESTS (S.I. UNITS)

Casting	Environmental condition	Test condition	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
6503	A5	ET	121.9	135.9	150.0	180.4	36.1	-
7028			134.8	146 6	155.2	181.2	39.6	31.9
P26			134.7	147.8	156.9	171.1	40.8	-
P65			133.1	138.4	144.7	154.3	39.4	7.8
6503	A5	RT	158.0	170.7	174.4	250.7	43.1	9.7
7028			156.5	169.9	196.1	268.0	44.4	7.2
P26			163.4	178.1	202.8	250.2	44.3	7.0
P65			170.7	183.3	211.6	250.0	45.0	6.8
6681	A6	ET	111.7	118.5	122.2	130.8	41.4	7.0
7029			111.0	120.0	126.3	145.8	39.2	-
P53			-	-	NO RESULTS AVAILABLE		-	-
P68			130.8	139.3	145.2	152.7	41.0	-
6681	A6	RT	157.8	170.7	195.1	262.2	47.0	7.3
7029			151.8	165.6	194.1	256.4	48.0	5.8
P53			167.6	182.9	211.9	253.9	44.3	5.5
P68			170.4	185.7	-	241.7	-	3.0
6103	A7	ET	116.9	126.6	131.1	148.7	41.6	11.8
6110			111.2	122.2	126.2	146.4	38.2	9.8
P36			-	-	NO RESULTS AVAILABLE		-	-
P75								
6103	A7	RT	145.3	158.8	183.8	261.9	46.1	11.2
6110			142.9	154.0	179.5	258.4	46.1	8.6
P36			158.3	171.3	195.4	250.8	44.5	4.7
P75			155.8	170.7	195.1	240.6	45.2	9.6
6104	A8	ET	127.7	137.3	141.9	153.5	44.0	-
6112			119.5	127.6	132.4	149.5	40.1	-
P50			-	-	NO RESULTS AVAILABLE		-	-
P80			-	SPECIMENS OVERHEATED AT INCLUSIONS				-
6104	A8	RT	149.8	161.2	187.3	255.1	46.5	4.5
6112			137.3	149.8	175.3	240.9	44.0	4.6
P50			163.4	174.5	198.6	249.9	47.4	4.1
P80			159.5	172.7	215.6	220.2	46.0	4.2

Table 8B (Cont'd)

LONG TERM ENVIRONMENTAL TENSILE TESTS (IMPERIAL UNITS)

Casting	Environmental condition	Test condition	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus × 10^{-6} lbf in^{-2}	Percentage elongation %
6503	A5	ET	7.89	8.80	9.71	11.68	5.23	-
7028			8.73	9.49	10.05	11.73	5.75	31.9
P26			8.72	9.57	10.16	11.08	5.92	-
P65			8.62	8.96	9.37	9.99	5.71	7.8
6503	A5	RT	10.23	11.05	11.29	16.23	6.25	9 7
7028			10.13	11.00	12.70	17.35	6.44	7.2
P26			10.58	11.53	13.13	16.20	6.43	7.0
P65			11.05	11.87	13.70	16.19	6.53	6.8
6681	A6	ET	7.23	7.67	7.91	8.47	6.00	7.0
7029			7.19	7.77	8.18	9.44	5.69	-
P53			-	-	NO RESULTS AVAILABLE		-	-
P68			8.47	9.02	9.40	9.89	5.94	-
6681	A6	RT	10.22	11.05	12.63	16.98	6.81	7.3
7029			9.83	10.72	12 57	16.60	6.96	5.8
P53			10.85	11.84	13.72	16.44	6.43	5.5
P68			11.03	12.03	-	16.59	-	3.0
6103	A7	ET	7.57	8.20	8.49	9.63	6.03	11.8
6110			7.20	7.91	8.17	9.48	5.54	9.8
P36			} -	-	NO RESULTS AVAILABLE		-	-
P75								
6103	A7	RT	9.41	10.28	11.90	16.96	6.68	11.2
6110			9.25	9.97	11.62	16.73	6.68	8.6
P36			10.25	11.09	12.65	16.24	6.45	4.7
P75			10.09	11.05	12.63	15.58	6.55	9.6
6104	A8	ET	8.27	8.89	9.19	9.94	6.38	-
6112			7.74	8.26	8.57	9.68	5.82	-
P50			-	NO RESULTS AVAILABLE			-	-
P80			-	SPECIMENS OVERHEATED AT INCLUSIONS				-
6104	A8	RT	9.70	10.44	12.13	16.52	6.74	4.5
6112			8.89	9.70	11.35	15.60	6.38	4.6
P50			10.58	11.30	12.86	16.18	6.88	4.1
P80			10.33	11.18	13.96	14.26	6.67	4.2

Table 8A (Cont'd)

LONG TERM ENVIRONMENTAL TENSILE TESTS (S.I. UNITS)

Casting	Environmental condition	Test condition	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
6498	A9	ET	115.7	121.7	126.0	134.5	41.6	-
6262			119.5	127.6	132.4	149.5	40.1	-
P16			122.5	128.8	131.7	153.4	42.4	-
P47			117.5	121.2	123.7	138.1	37.0	-
6498	A9	RT	164.3	179.0	202.2	251.7	44.1	6.3
6262			138.2	151.0	177.9	239.8	46.5	7.0
P16			149.7	163.4	190.3	238.9	44.1	7.8
P47			162.0	177.0	203.6	254.2	46.1	2.1
6106	A10	ET	93.9	116.5	124.8	138.2	45.8	-
6257			126.2	135.0	139.0	159.8	49.5	-
P9			125.9	134.2	139.0	154.6	42.0	-
P24			135.4	137.3	137.5	153.2	41.0	-
6106	A10	RT	151.2	164.5	191.4	263.3	45.7	9.8
6257			167.9	182.9	211.9	257.0	44.3	5.5
P9			162.5	177.1	205.9	255.1	45.4	3.8
P24			157.1	174.1	201.7	261.0	44.4	4.8
6684	A11	ET	120.2	127.1	138.2	146.3	43.4	-
7033			104.9	111.0	117.7	129.1	43.9	-
P37			107.3	111.7	115.2	120.5	43.7	-
P72			111.8	115.4	119.5	123.4	43.4	-
6684	A11	RT	159.1	172.2	198.9	248.0	49.1	5.8
7033			134.5	147.8	172.0	221.5	41.2	6.1
P37			161.2	173.9	193.8	246.2	45.5	5.1
P72			155.7	172.2	200.5	235.1	45.6	9.0
6501	A12	ET	111.4	122.5	127.3	148.9	40.1	-
7031			109.0	118.5	122.3	144.1	42.8	-
P29			97.5	102.2	106.3	120.6	38.7	-
P66			91.3	95.0	100.2	112.6	40.6	-
6501	A12	RT	143.6	157.8	185.2	253.3	44.1	10.0
7031			139.8	152.4	177.8	229.8	46.7	9.0
P29			97.8	102.2	106.3	120.6	38.7	-
P66			136.8	155.4	177.6	228.6	50.3	3.8

Table 8B (Cont'd)

LONG TERM ENVIRONMENTAL TENSILE TESTS (IMPERIAL UNITS)

Casting	Environmental condition	Test condition	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus $\times 10^{-6}$ lbf in^{-2}	Percentage elongation %
6498	A9	ET	7.49	7.88	8.16	8.71	6.03	-
6262	A9	ET	7.74	8.26	8.57	9.68	5.82	-
P16	A9	ET	7.93	8.34	8.53	9.93	6.15	-
P47	A9	ET	7.61	7.85	8.01	8.49	5.37	-
6498	A9	RT	10.64	11 59	13.09	16.30	6.39	6.3
6262	A9	RT	8.95	9.78	11.52	15.53	6.74	7.0
P16	A9	RT	9.69	10.58	12.32	15.47	6.40	7.8
P47	A9	RT	10.49	11.46	13.18	16 46	6.68	2.1
6106	A10	ET	6 08	7.54	8.08	8.95	6.64	-
6257	A10	ET	8.17	8.74	9.00	10.35	7.18	-
P9	A10	ET	8.15	8.69	9.00	10.01	6.09	-
P24	A10	ET	8.77	8.89	8.90	9.92	5.95	-
6106	A10	RT	9.79	10.65	12.39	17.05	6.63	9.8
6257	A10	RT	10.87	11.84	13.72	16.64	6.43	5.5
P9	A10	RT	10.52	11.47	13.33	16.52	6.58	3.8
P24	A10	RT	10.17	11.27	13.06	16.90	6.44	4.8
6684	A11	ET	7.78	8.23	8.95	9.47	6.29	-
7033	A11	ET	6.79	7.19	7.62	8.36	6.37	-
P37	A11	ET	6.95	7.23	7.46	7.80	6.34	-
P72	A11	ET	7.24	7.47	7.74	7.99	6.30	-
6684	A11	RT	10 30	11.15	12.88	16.06	7.12	5.8
7033	A11	RT	8.73	9.57	11.14	14.34	5.97	6.1
P37	A11	RT	10 44	11.26	12.55	15.94	6.60	5.1
P72	A11	RT	10.08	11.15	12.98	15.22	6.61	9.0
6501	A12	ET	7.21	7.93	8.28	9.64	5.82	-
7031	A12	ET	7.06	7.67	7.92	9.33	6.21	-
P29	A12	ET	6.31	6.62	6.88	7.81	5.62	-
P66	A12	ET	5.91	6.15	6.49	7.29	5.89	-
6501	A12	RT	9.30	10.22	11.99	16.40	6.40	10.0
7031	A12	RT	9 05	9.87	11.51	14.88	6.77	9.0
P29	A12	RT	6.33	6.62	6.88	7.81	5.62	-
P66	A12	RT	8.86	10.06	11.50	14.80	7.29	3.8

Table 9A

SHORT TERM ENVIRONMENTAL TENSILE TESTS (S.I. UNITS)

Casting	Environmental condition	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}
6108	B1	115.7	135.1	143.0	159.2	40.5
6263	B1	143.5	152.0	159.5	178.4	41.5
P38	B1	127.9	135.4	138.8	156.6	43.7
P67	B1	139.0	144.6	153.1	158.6	43.8
6108	B2	109.0	115.4	125.9	140.1	42.5
6263	B2	126.0	131.0	139.2	140.5	41.4
P38	B2	99.3	107.2	113.1	127.7	41.0
P67	B2	109.5	117.5	121.7	132.0	42.1
6502	B3	90.0	96.5	104.7	129.7	34.4
7034	B3	109.5	124.2	132.8	128.5	41.5
P17	B3	69.7	77.1	85.9	101.3	33.5
P73	B3	56.2	60.2	65.0	95.6	27.9
6502	B4	68.4	75.4	87.7	91.6	38.7
7034	B4	88.5	95.4	94.2	88.3	41.2
P17	B4	49.0	57.1	64.1	99.6	27.2
P73	B4	40.8	44.2	47.4	84.6	25.4
6685	B5	99.3	107.0	112.1	130.8	32.9
7035	B5	98.8	114.0	128.2	136.4	35.3
P30	B5	99.2	100.5	-	101.3	35.9

Table 9B

SHORT TERM ENVIRONMENTAL TENSILE TESTS (IMPERIAL UNITS)

Casting	Environmental condition	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus $\times 10^{-6}$ lbf in^{-2}
6108	B1	7.49	8.75	9.26	10.31	5.88
6263	B1	9.29	9.84	10.33	11.55	6.02
P38	B1	8.28	8.77	8.99	10.14	6.34
P67	B1	9.00	9.36	9.91	10.27	6.35
6108	B2	7.06	7.47	8.15	9.07	6.16
6263	B2	8.16	8.48	9.01	9.10	6.01
P38	B2	6.43	6.94	7.32	8.27	5.95
P67	B2	7.09	7.61	7.88	8.55	6.11
6502	B3	5.83	6.25	6.78	8.40	4.99
7034	B3	7.09	8.04	8.60	8.32	6.03
P17	B3	4.51	4.99	5.50	6.56	4.86
P73	B3	3.64	3.90	4.21	6.19	4.04
6502	B4	4.43	4.88	5.68	5.93	5.62
7034	B4	5.73	6.18	6.10	5.72	5.97
P17	B4	3.17	3.70	4.15	6.45	3.95
P73	B4	2.64	2.86	3.07	5.48	3.68
6685	B5	6.43	6.93	7.26	8.47	4.77
7035	B5	6.40	7.38	8.30	8.83	5.12
P30	B5	6.42	6.57	-	6.56	5.21

Table 10A

SUMMARY OF MEAN VALUES - LONG TERM ENVIRONMENTAL TENSILE TESTS (S.I. UNITS)

Environmental condition	Test condition	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
None	RT	162.9	176.7	205.6	264.4	47.5	7.83
A1	ET	146.7	156.8	167.0	193.8	36.6	31.35
A1	RT	165.7	179.2	206.3	272.6	47.3	7.70
None	RT	162.4	176.5	203.7	257.9	46.2	6.03
A2	ET	143.3	152.7	161.1	183.9	41.0	21.73
A2	RT	165.9	180.9	203.8	255.0	45.2	7.50
None	RT	162.0	178.1	204.0	258.7	45.9	6.48
A3	ET	145.9	154.8	166.5	188.4	44.5	-
A3	RT	163.2	177.1	202.0	245.3	47.8	5.55
None	RT	158.5	172.4	202.3	244.5	45.4	4.68
A4	ET	138.8	148.6	157.2	182.6	41.4	-
A4	RT	162.3	175.9	201.2	248.8	45.0	5.75
None	RT	160.9	176.1	202.9	253.6	45.4	6.30
A5	ET	131.1	142.2	151.7	171.7	39.0	19.85
A5	RT	162.5	175.4	196.3	254.7	44.2	7.68
None	RT	151.0	167.9	194.3	242.5	44.8	8.73
A6	ET	117.8	125.9	131.3	143.2	40.1	7.00
A6	RT	161.9	176.2	200.3	253.6	46.4	5.40
None	RT	152.0	165.9	185.3	257.6	45.3	8.28
A7	ET	114.1	124.5	128.7	147.6	39.9	10.80
A7	RT	150.6	163.4	188.4	253.0	45.4	8.53
None	RT	154.8	167.7	195.4	252.5	46.8	7.00
A8	ET	123.7	132.5	137.1	151.5	42.1	-
A8	RT	152.6	164.6	194.3	241.5	46.0	4.35

Table 10B

SUMMARY OF MEAN VALUES - LONG TERM ENVIRONMENTAL TENSILE TESTS (IMPERIAL UNITS)

Environmental condition	Test condition	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus × 10^{-6} lbf in^{-2}	Percentage elongation %
None	RT	10.55	11.44	13.31	17.12	6.89	7.83
A1	ET	9.49	10.15	10.81	12.55	5.60	31.35
A1	RT	10.73	11.60	13.36	17.65	6.86	7.70
None	RT	10.52	11.43	13.19	16.70	6.70	6.03
A2	ET	9.28	9.89	10.43	11.91	5.95	21.73
A2	RT	10.74	11.71	13.20	16.51	6.55	7.50
None	RT	10.49	11.56	13.21	16.75	6.65	6.48
A3	ET	9.45	10.02	10.78	12.20	6.46	-
A3	RT	10.57	11.47	13.08	15.88	6 49	5.55
None	RT	10.26	11.16	13.10	15.83	6.58	4.68
A4	ET	8.99	9.62	10.18	11.82	6.00	-
A4	RT	10.51	11.39	13.03	16.11	6.53	5.75
None	RT	10 43	11.40	13.14	16.42	6.58	6.30
A5	ET	8.49	9.21	9.82	11.12	5.65	19.85
A5	RT	10.52	11.36	12.71	16.49	6.41	7.68
None	RT	9.78	10.87	12.58	15.70	6.50	8.73
A6	ET	7.63	8.15	8.50	9 27	5.88	7.00
A6	RT	10.48	11.41	12.97	16.42	6.73	5.40
None	RT	9.84	10.74	12.00	16.68	6.57	8.28
A7	ET	7.39	8.06	8.33	9.56	5.79	10.80
A7	RT	9.75	10.60	12.20	16.38	6.59	8.53
None	RT	10.02	10.86	12.65	16.35	6.79	7.00
A8	ET	8.01	8.58	8.88	9.81	6.10	-
A8	RT	9.88	10.66	12.58	15.64	6.67	4.35

Table 10A (Cont'd)

SUMMARY OF MEAN VALUES - LONG TERM ENVIRONMENTAL TENSILE TESTS (S.I. UNITS)

Environmental condition	Test condition	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}	Percentage elongation %
None	RT	154.3	168.3	198.0	230.7	44.4	4.63
A9	ET	118.8	124.8	128.5	142.1	40.3	-
A9	RT	153.5	176.6	193.5	246.2	45.2	5.80
None	RT	155.1	169.7	198.9	253.0	47.2	6.45
A10	ET	120.3	130.8	135.1	151.5	44.6	-
A10	RT	159.7	174.7	202.9	259.2	45.0	5.98
None	RT	157.8	172.4	198.9	249.1	46.0	4.23
A11	ET	111.0	116.3	122.6	129.9	43.6	-
A11	RT	152.7	166.5	191.4	237.7	45.4	6.50
None	RT	160.5	175.3	204.5	251.6	46.7	5.55
A12	ET	102.2	109.5	114.0	131.6	40.6	-
A12	RT	129.6	141.9	161.7	208.0	45.0	7.60

Table 10B (Cont'd)

SUMMARY OF MEAN VALUES - LONG TERM ENVIRONMENTAL TENSILE TESTS (IMPERIAL UNITS)

Environmental condition	Test condition	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus $\times 10^{-6}$ lbf in^{-2}	Percentage elongation %
None	RT	9.99	10.90	12.82	14.94	6.44	4.63
A9	ET	7.69	8.08	8.32	9.20	5.84	-
A9	RT	9.94	10.85	12.53	15.94	6.55	5.80
None	RT	10.04	10.99	12.88	16.38	6.85	6.45
A10	ET	7.79	8.47	8.75	9.81	6.47	-
A10	RT	10.34	11.31	13.14	16.78	6.52	5.98
None	RT	10.22	11.16	12.88	16.13	6.67	4.23
A11	ET	7.19	7.53	7.94	8.41	6.33	-
A11	RT	9.89	10.78	12.39	15.39	6.58	6.50
None	RT	10.39	11.35	13.24	16.29	6.78	5.55
A12	ET	6.62	7.09	7.38	8.52	5.89	-
A12	RT	8.39	9.19	10.47	13.47	6.52	7.60

Table 11A

SUMMARY OF MEAN VALUES - SHORT TERM ENVIRONMENTAL TENSILE TESTS (S.I. UNITS)

Environmental condition	Test condition	0.1% proof stress MN m^{-2}	0.2% proof stress MN m^{-2}	0.5% proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Young's modulus GN m^{-2}
None	RT	157.8	171.9	199.7	243.9	47.2
B1	ET	131.6	141.8	148.5	163.2	42.4
None	RT	151.8	171.9	199.7	243.9	47.2
B2	ET	111.0	117.8	124.9	135.1	41.8
None	RT	160.3	175.1	193.5	251.1	45.9
B3	ET	81.4	89.6	97.1	113.8	34.3
None	RT	160.3	175.1	193.5	251.1	45.9
B4	ET	61.6	68.1	73.4	91.1	33.2
None	RT	156.8	170.7	198.3	242.0	47.8
B5	ET	99.3	107.2	120.2	122.8	34.7

Table 11B

SUMMARY OF MEAN VALUES - SHORT TERM ENVIRONMENTAL TENSILE TESTS (IMPERIAL UNITS)

Environmental condition	Test condition	0.1% proof stress tonf in^{-2}	0.2% proof stress tonf in^{-2}	0.5% proof stress tonf in^{-2}	Ultimate stress tonf in^{-2}	Young's modulus $\times 10^{-6}$ lbf in^{-2}
None	RT	10.22	11.13	12.93	15.79	6.85
B1	ET	8.52	9.18	9.62	10.57	6.15
None	RT	10.22	11.13	12.93	15.79	6.85
B2	ET	7.19	7.63	8.09	8.75	6.06
None	RT	10.38	11.34	12.53	16.26	6.65
B3	ET	5.27	5.80	6.29	7.37	4.98
None	RT	10.38	11.34	12.53	16.26	6.65
B4	ET	3.99	4.41	4.75	5.90	4.81
None	RT	10.15	11.05	12.84	15.67	6.93
B5	ET	6.42	6.94	7.78	7.95	5.03

Table 12

HEAT FACTORS AND RECOVERY HEAT FACTORS FROM TENSILE TESTS

Environmental condition	Heat factors		Recovery heat factors	
	0.1% proof stress	Ultimate stress	0.1% proof stress	Ultimate stress
A1	0.901	0.733	1.017	1.031
A2	0.882	0.713	1.021	0.899
A3	0.901	0.728	1.008	0.948
A4	0.876	0.747	1.024	1.078
A5	0.815	0.677	1.010	0.978
A6	0.780	0.590	1.072	1.046
A7	0.781	0.573	0.991	0.982
A8	0.799	0.600	0.986	0.957
A9	0.776	0.616	0.995	1.067
A10	0.776	0.599	1.030	1.024
A11	0.704	0.521	0.968	0.954
A12	0.637	0.523	0.808	0.827
B1	0.837	0.669		
B2	0.704	0.554		
B3	0.508	0.453		
B4	0.384	0.363		
B5	0.633	0.507		

Table 13

TORSIONAL TESTS WITHOUT ENVIRONMENTAL HEATING

Manufacturer and batch	Casting	S.I. UNITS			IMPERIAL UNITS		
		Torsional proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Shear modulus GN m^{-2}	Torsional proof stress $\times 10^{-3}$ lbf in^{-2}	Ultimate stress $\times 10^{-3}$ lbf in^{-2}	Shear modulus $\times 10^{-6}$ lbf in^{-2}
A1	6674	71.73	157.57	17.39	10.40	22.85	2.522
	6101	57.49	123.20	16.42	8.34	17.87	2.382
	6494	83.59	166.35	18.57	12.12	24.13	2.694
A2	6109	70.86	156.57	18.62	10.28	22.71	2.701
	6252	78.65	159.09	18.27	11.41	23.09	2.659
	7024	75.60	158.70	18.13	10.97	23.02	2.629
B1	P10	81.86	173.75	18.19	11.87	25.20	2.638
	P49	81.86	173.54	19.03	11.87	25.17	2.760
	P13	87.40	177.27	18.60	12.68	25.71	2.697
B2	P64	86.38	170.46	17.62	12.53	24.72	2.556
	P19	82.45	170.96	17.92	11.96	24.80	2.599
	P79	85.19	167.26	17.93	12.36	24.26	2.601

Table 14

MEAN VALUES AND COEFFICIENTS OF VARIATION OF TORSIONAL TESTS WITHOUT ENVIRONMENTAL HEATING

Manufacturer	Batch	S.I. UNITS			IMPERIAL UNITS		
		Torsional proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Shear modulus GN m^{-2}	Torsional proof stress $\times 10^{-3}$ lbf in^{-2}	Ultimate stress $\times 10^{-3}$ lbf in^{-2}	Shear modulus $\times 10^{-6}$ lbf in^{-2}
A	1	70.52	149.04	17.43	10.23	21.62	2.533
A	2	75.04	158.12	18.34	10.88	22.93	2.663
A	1 + 2	72.99	153.58	17.90	10.59	22.28	2.598
B	1	83.70	174.85	18.60	12.14	25.36	2.698
B	2	84.68	169.56	17.81	12.28	24.59	2.585
B	1 + 2	84.19	172.20	18.22	12.21	24.98	2.642
All batches		78.84	162.90	18.06	11.44	23.63	2.620
Coefficients of variation for Manufacturer A based on 6 specimens		12.21%	9.96%	4.33%			
Coefficients of variation for Manufacturer B based on 6 specimens		3.89%	1.99%	2.59%			
Overall coefficient of variation based on 12 specimens		11.06%	8.81%	3.36%			

Table 15

LONG TERM ENVIRONMENTAL TORSION TESTS

Manufacturer and batch	Environmental condition	Casting	S.I. UNITS			IMPERIAL UNITS		
			Torsional proof stress MN m^{-2}	Ultimate stress MN m^{-2}	Shear modulus GN m^{-2}	Torsional proof stress $\times 10^{-3}$ lbf in^{-2}	Ultimate stress $\times 10^{-3}$ lbf in^{-2}	Shear modulus $\times 10^{-6}$ lbf in^{-2}
A1	A6	6105	73.3	162.7	15.5	10.63	23.60	2.250
		6500	84.8	129.8	15.7	12.30	18.82	2.277
A2	A6	6113	71.5	149.2	15.4	10.36	21.64	2.226
		6261	75.8	163.3	15.5	11.00	23.68	2.249
B1	A6	P15	79.0	171.4	16.1	11.46	24.86	2.327
		P16	87.1	179.4	16.2	12.63	26.02	2.342
B2	A6	P22	78.5	172.7	16.1	11.39	25.05	2.328
		P45	81.5	175.9	16.1	11.83	25.50	2.338
A1	A10	6499	82.1	172.6	15.7	11.81	24.88	2.275
		6683	79.5	128.9	15.7	11.53	18.69	2.277
A2	A10	6116	69.6	152.7	15.2	10.09	22.14	2.208
		7030	78.0	169.2	14.7	11.32	24.54	2.132
B1	A10	P27	83.9	179.8	15.9	12.17	26.08	2.311
		P32	79.1	176.9	15.7	11.48	25.66	2.283
B2	A10	P59	84.8	172.9	15.8	12.31	25.07	2.290
		P70	87.2	173.5	16.0	12.65	25.17	3.319
Mean value	A6		78.9	162.9	15.8	11.44	23.63	2.292
Mean value	A10		80.5	165.7	15.6	11.68	24.03	2.263

Table 16

RECOVERY HEAT FACTORS FOR LONG TERM ENVIRONMENTAL TORSION TESTS

Environmental condition	Recovery heat factor	
	Proof stress	Ultimate stress
A6	1.001	1.000
A10	1.021	1.017

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No.	Author	Title, etc.
1	I. G. Bowen	Strength tests on light alloy castings. Flight Refuelling Ltd. Sc. & Tech. Memorandum 5/44 (1944)
2	Ministry of Technology	Design requirements for service aircraft. Leaflet 401/5, Para. 1.1 Mintech Av.P. 970
3	Ministry of Technology	Design requirements for service aircraft. Leaflet 406/1, Para. 2.2 Mintech Av.P. 970
4	Mrs. P. M. Perrett D. F. Wright	The room temperature strength of light alloy castings to specification DTD 298A, DTD 721 and DTD 748 R.A.E. Technical Note Structures 283 (1960)
5	F. Clifton	The strength properties of some light alloy casting materials. R.A.E. Report Structures 160 (1954)

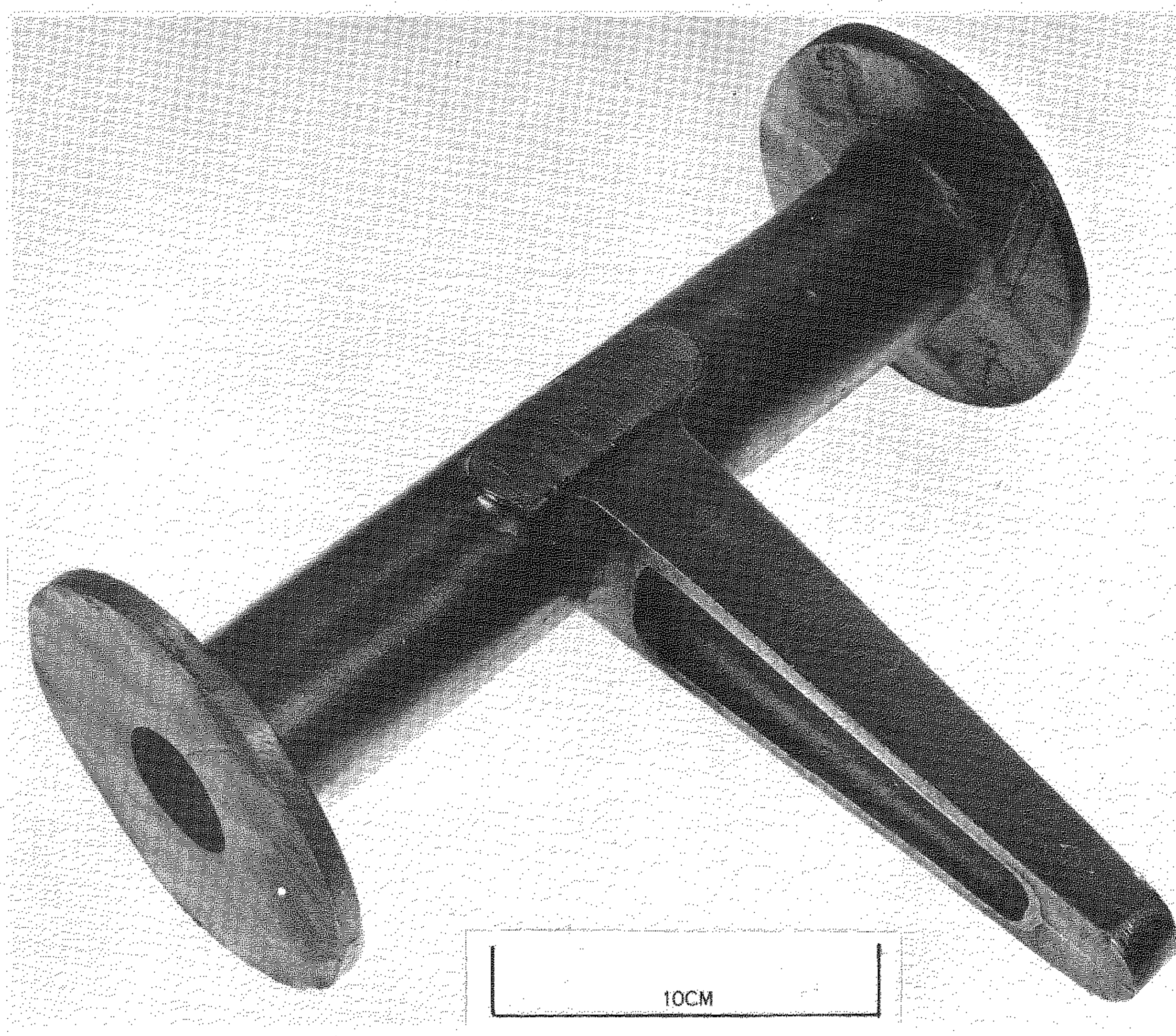


Fig.1. Standard J.A.C test casting

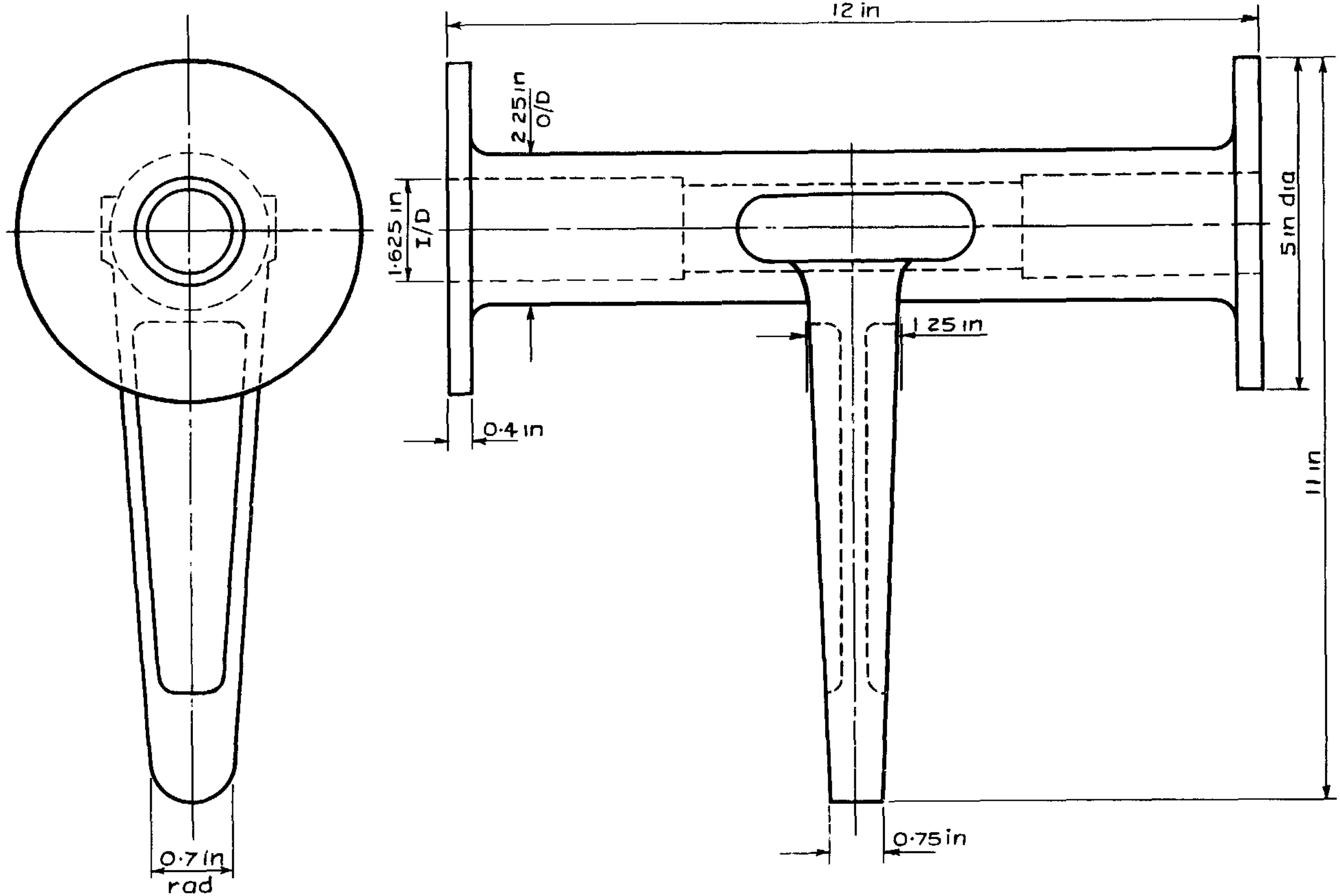
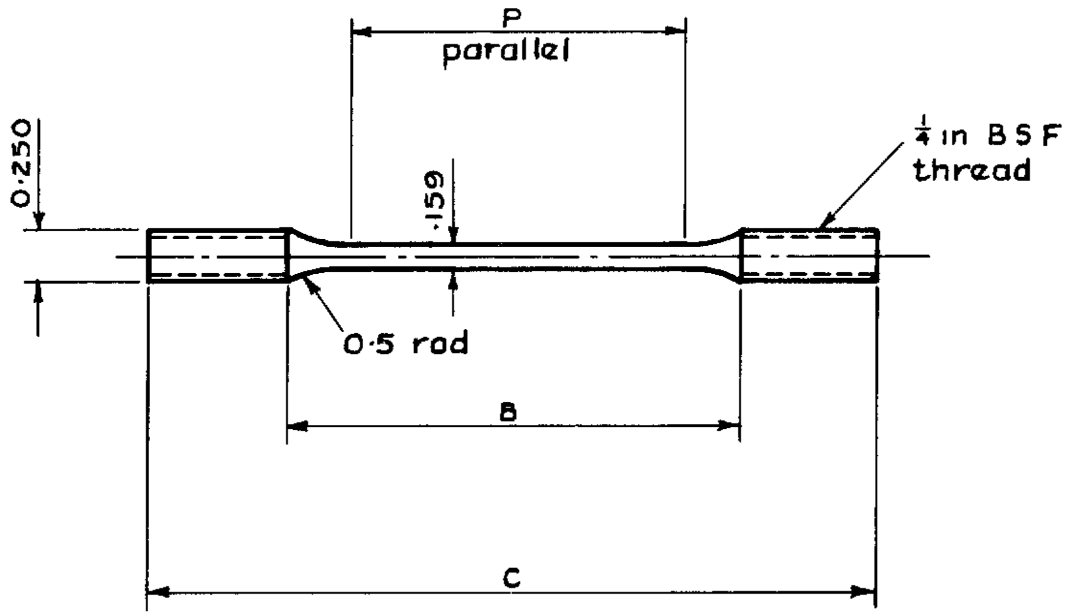


Fig.2 Standard J.A.C. test casting



Dimension	Room temperature test pieces	Elevated temperature test pieces
P	1 58	2·58
B	2·00	3·00
C	2·50	3·50

Dimensions in inches

Fig. 3 Tensile test pieces

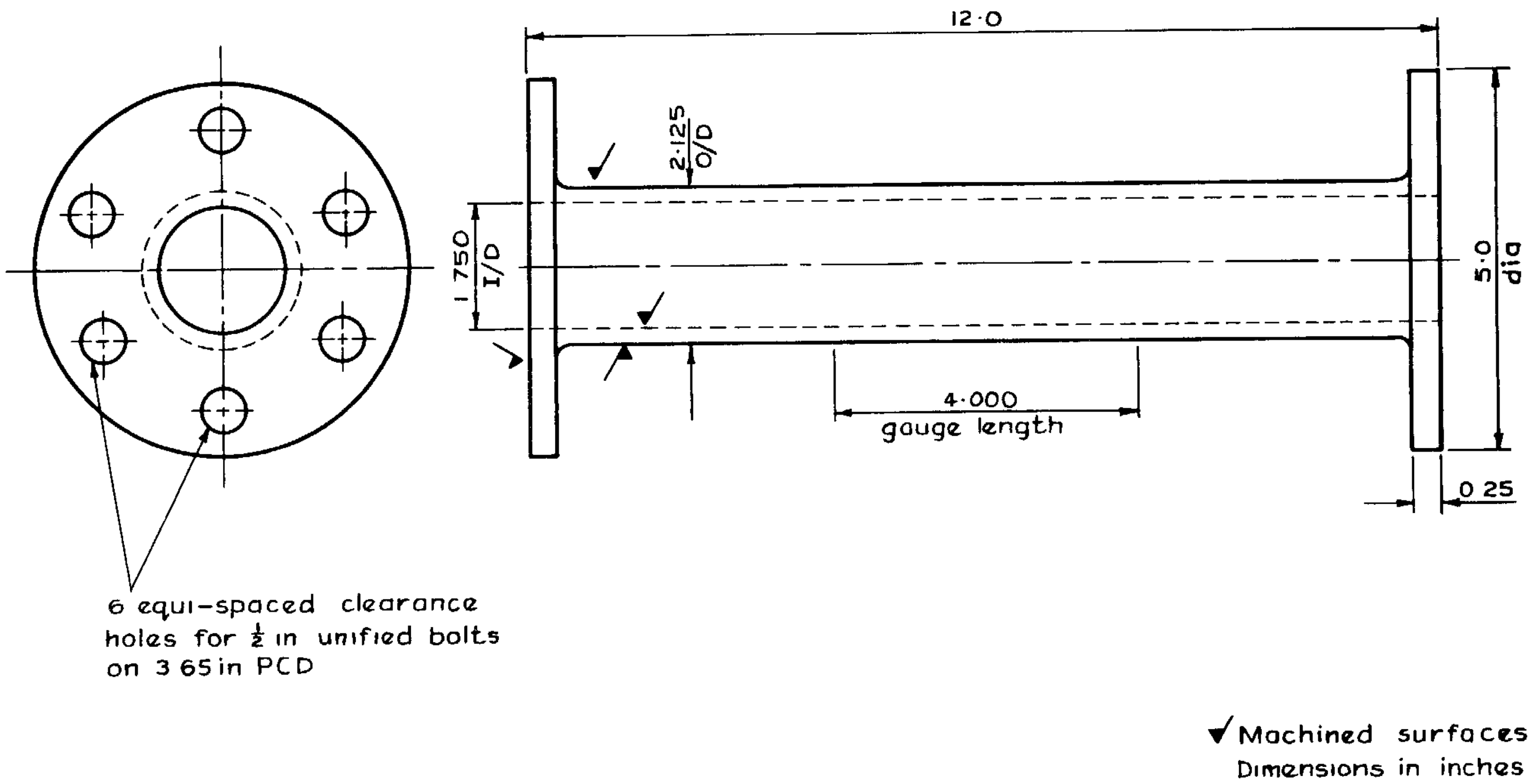


Fig.4 Torsion test piece

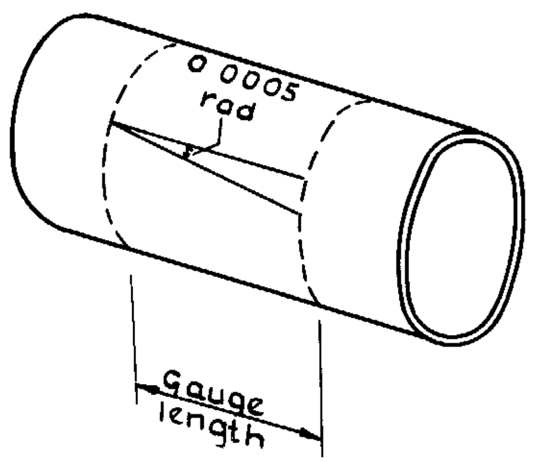


Fig. 5 Definition of permanent strain used to calculate torsional proof stress

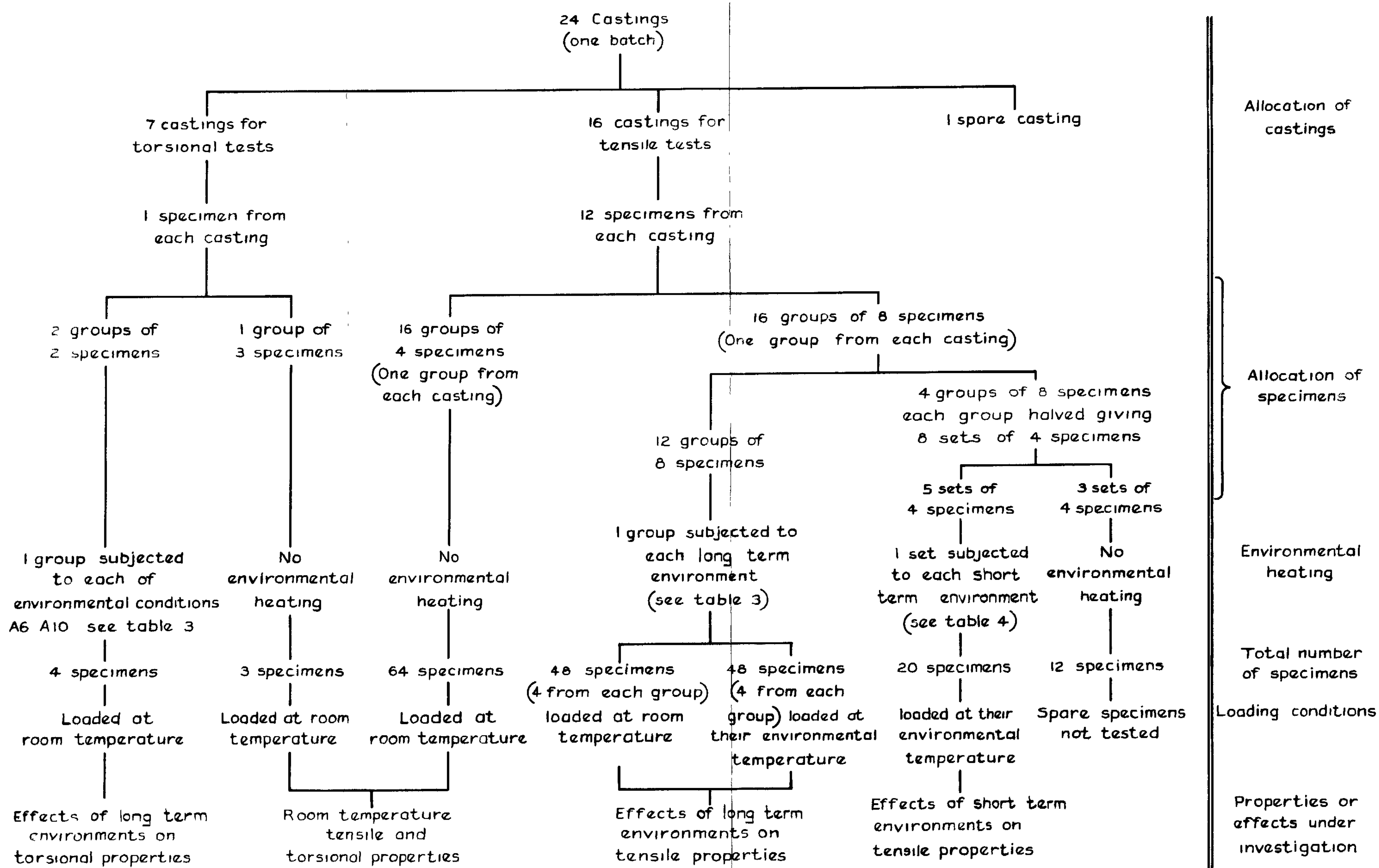


Fig. 6 Allocation of specimens from a single batch of castings

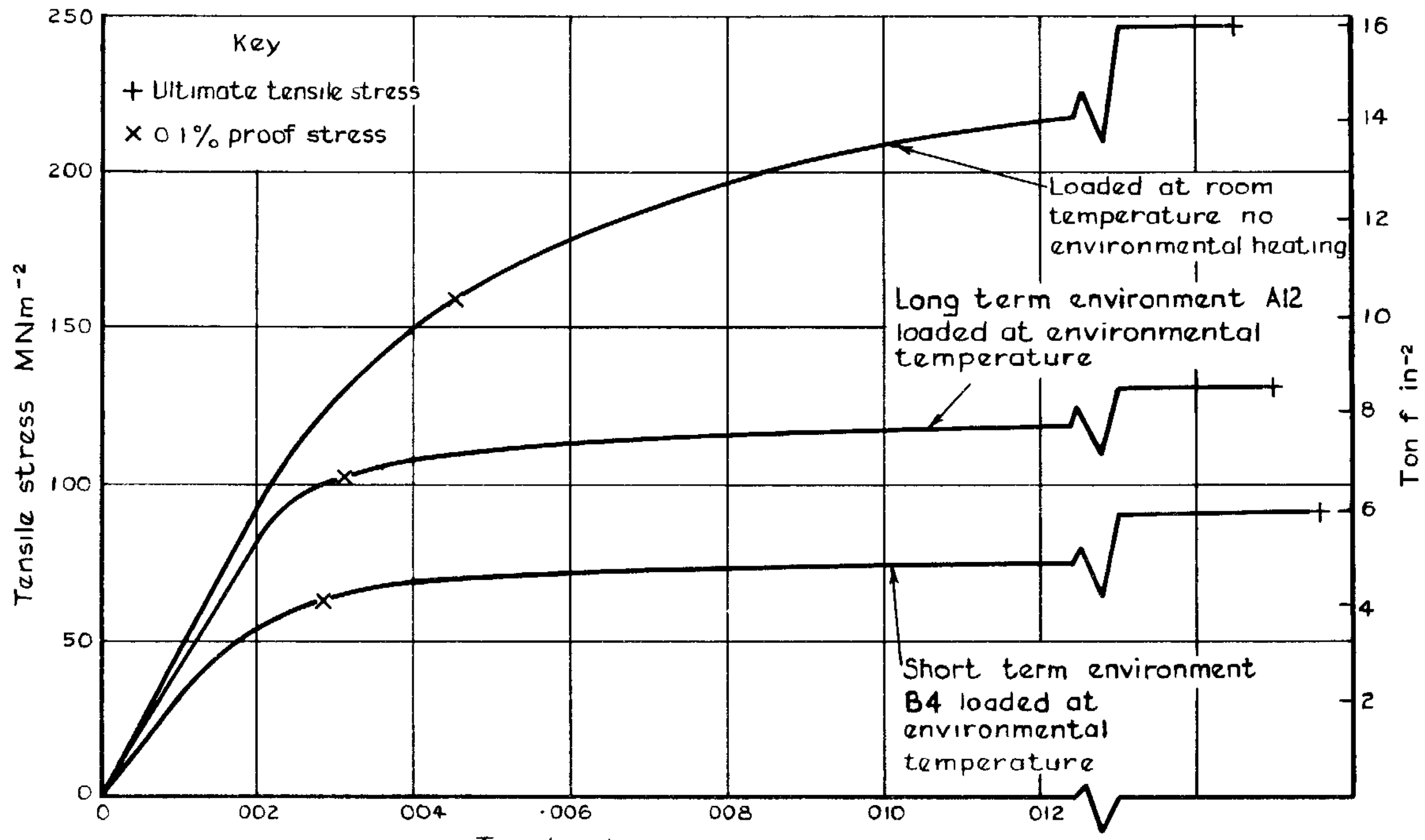


Fig.7 Typical stress-strain curves for various environmental conditions

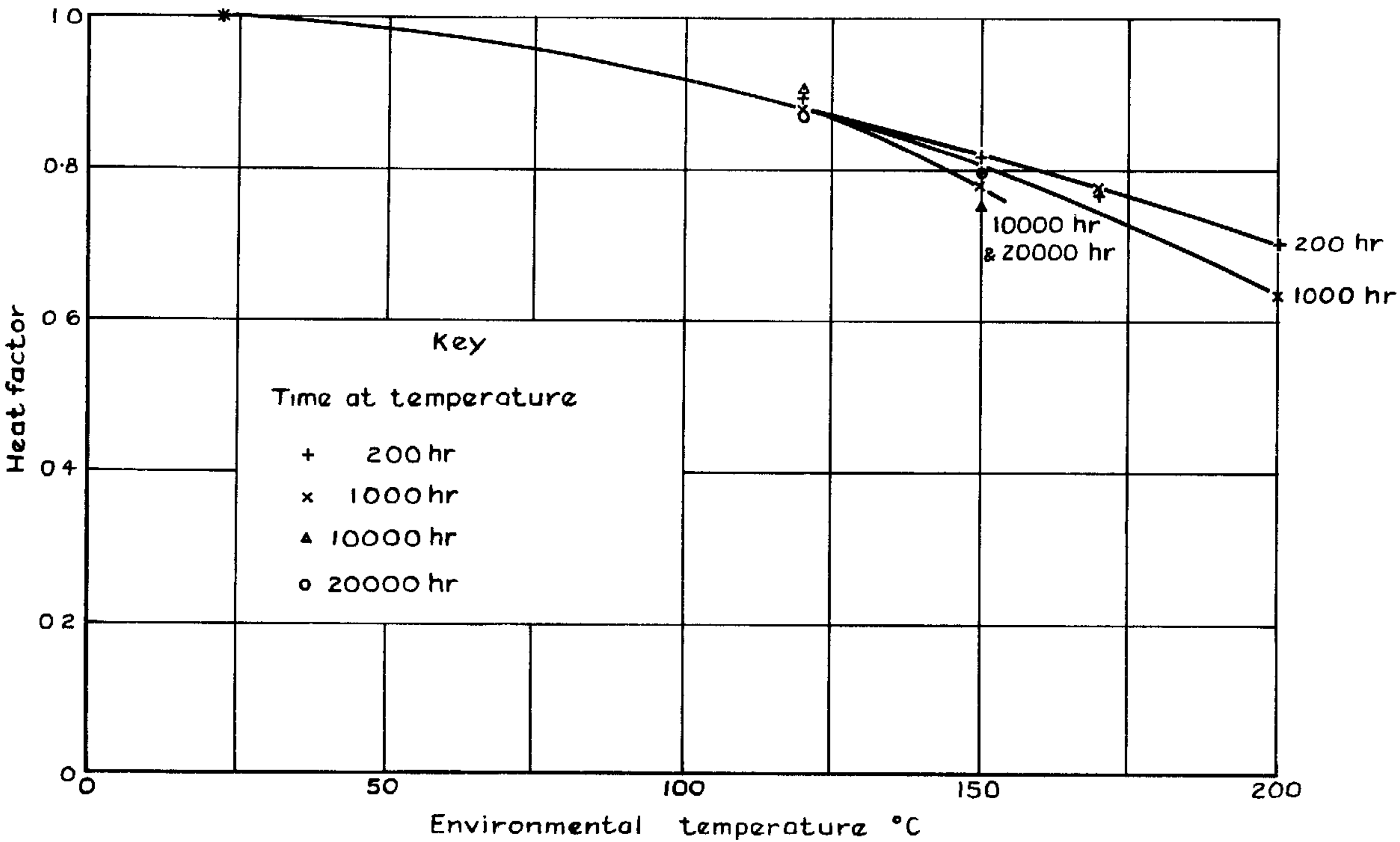


Fig. 8 Variation of heat factor for 0·1 % tensile proof stress with long term environmental temperature

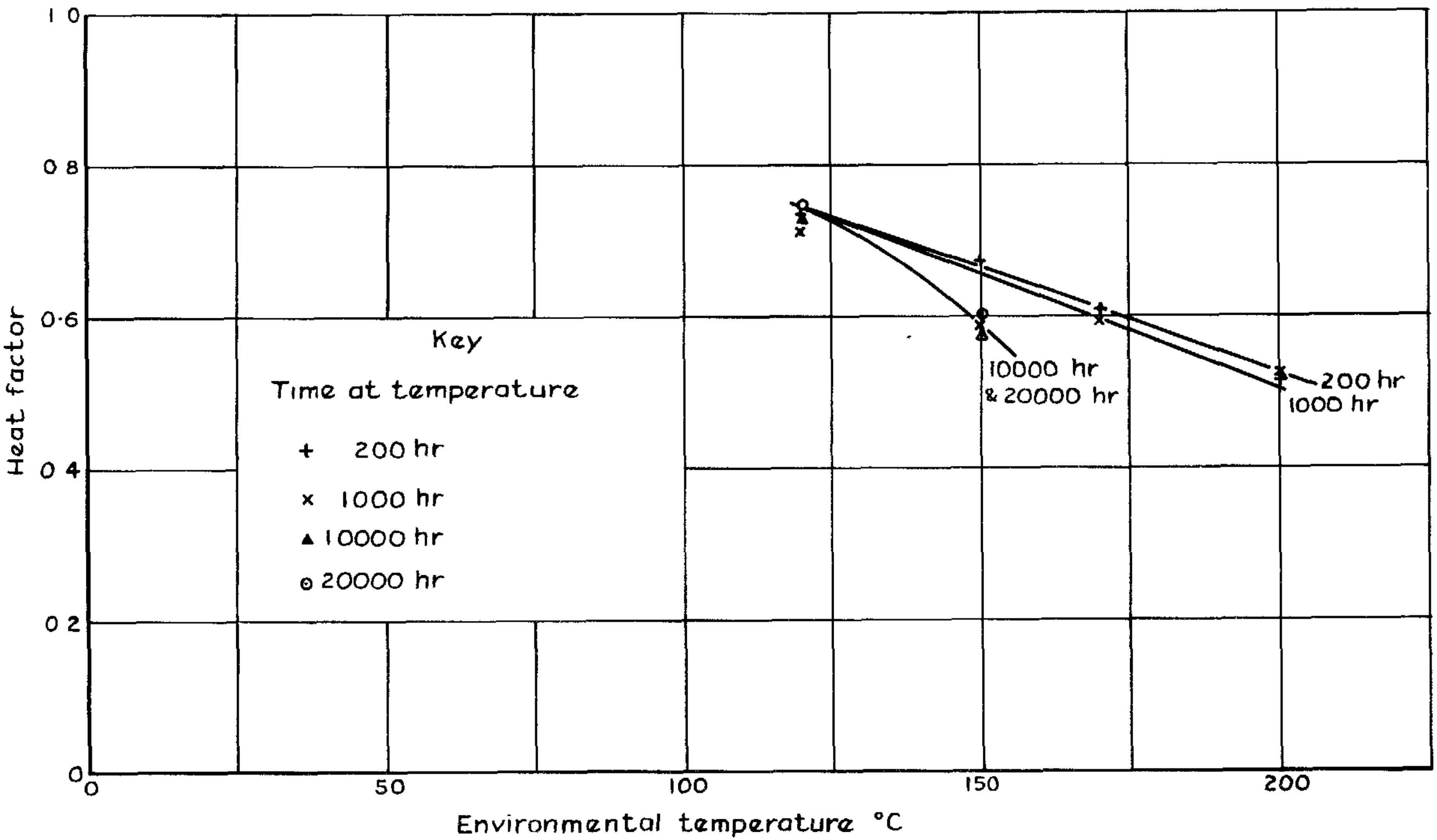


Fig.9 Variation of heat factor for ultimate tensile stress with long term environmental temperature

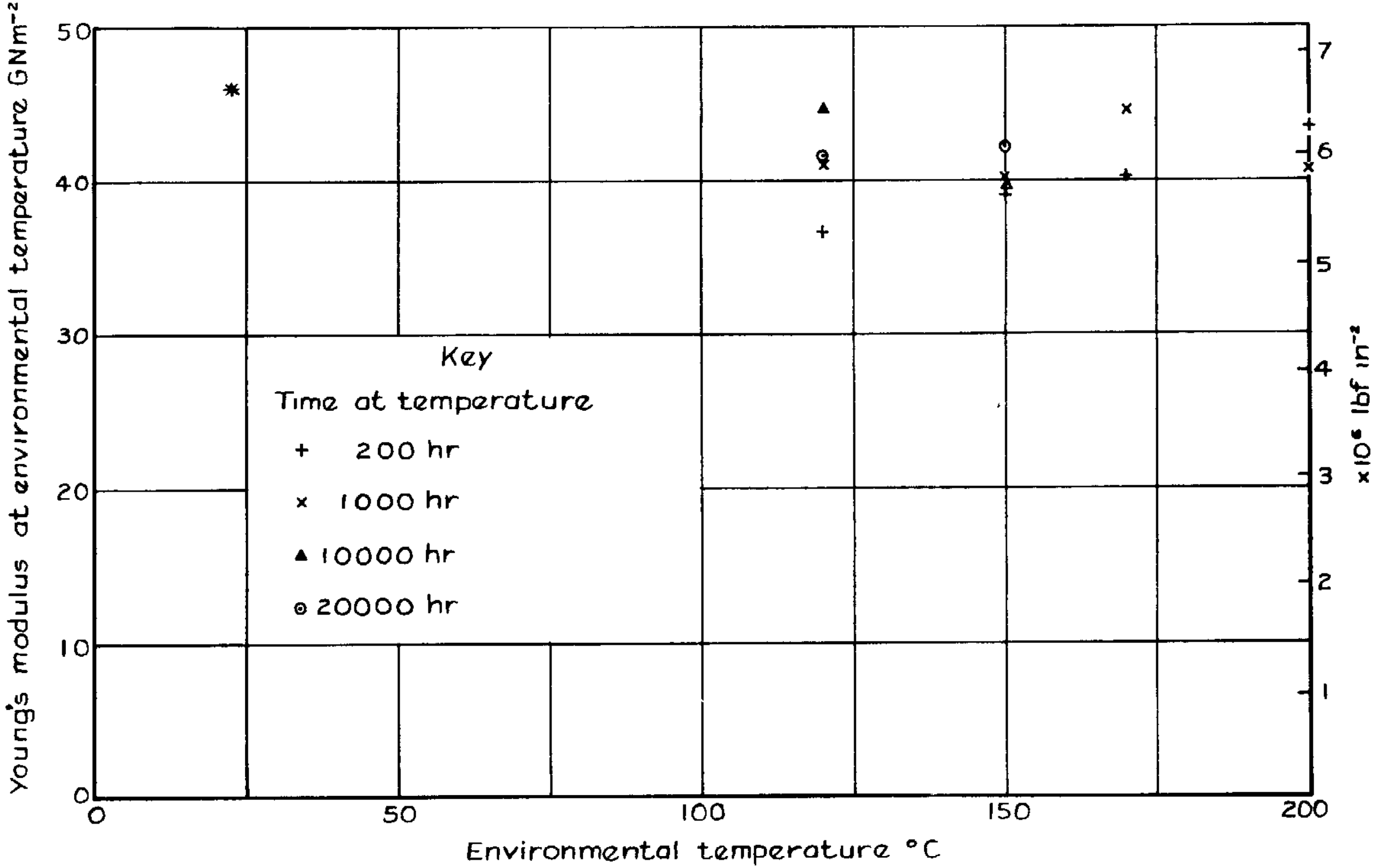


Fig.10 Variation of Young's modulus at elevated temperature with long term environmental temperature

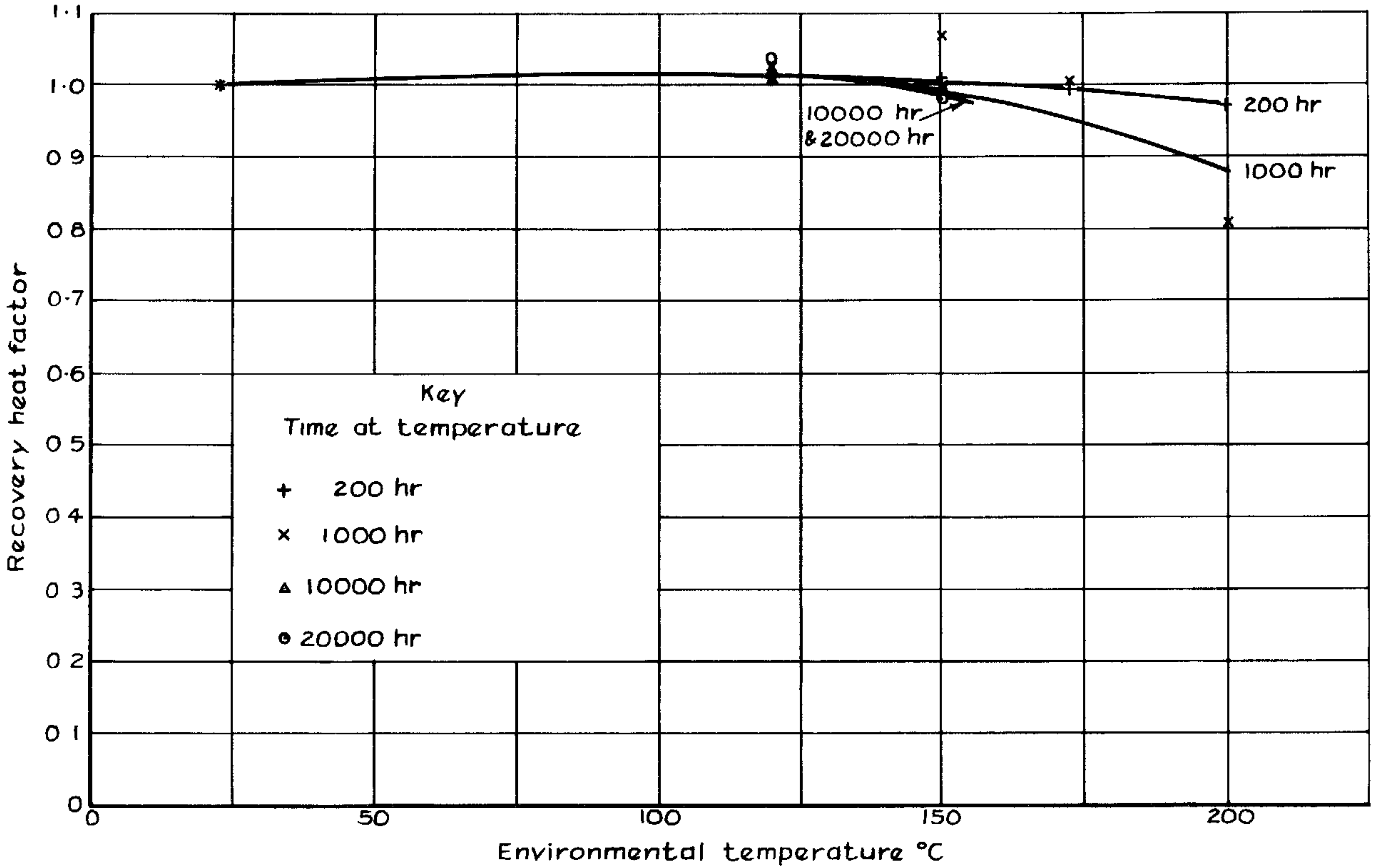


Fig. 11 Variation of recovery heat factor for 0·1% tensile proof stress with long term environmental temperature

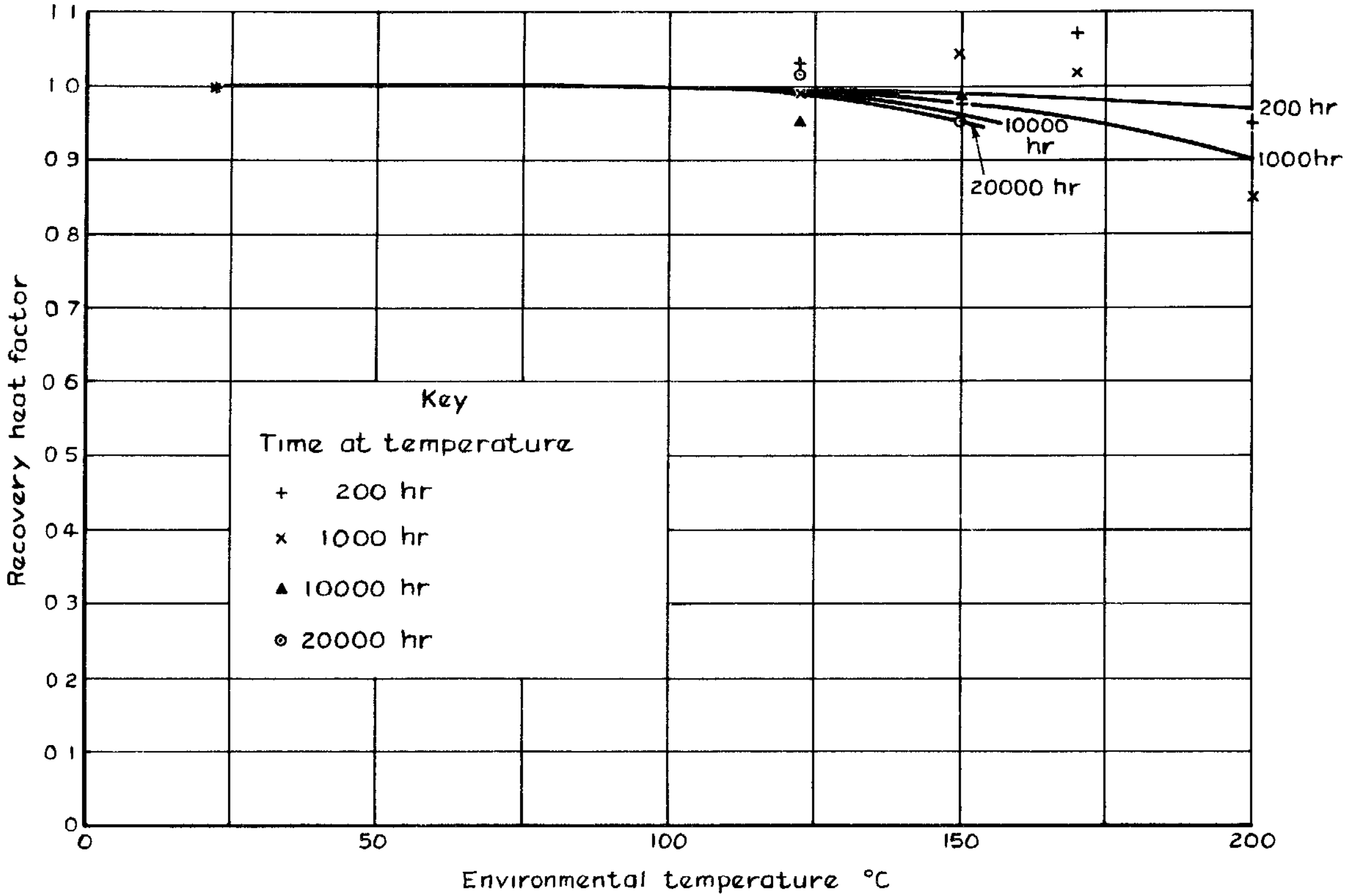


Fig. 12 Variation of recovery heat factor for ultimate tensile stress with long term environmental temperature

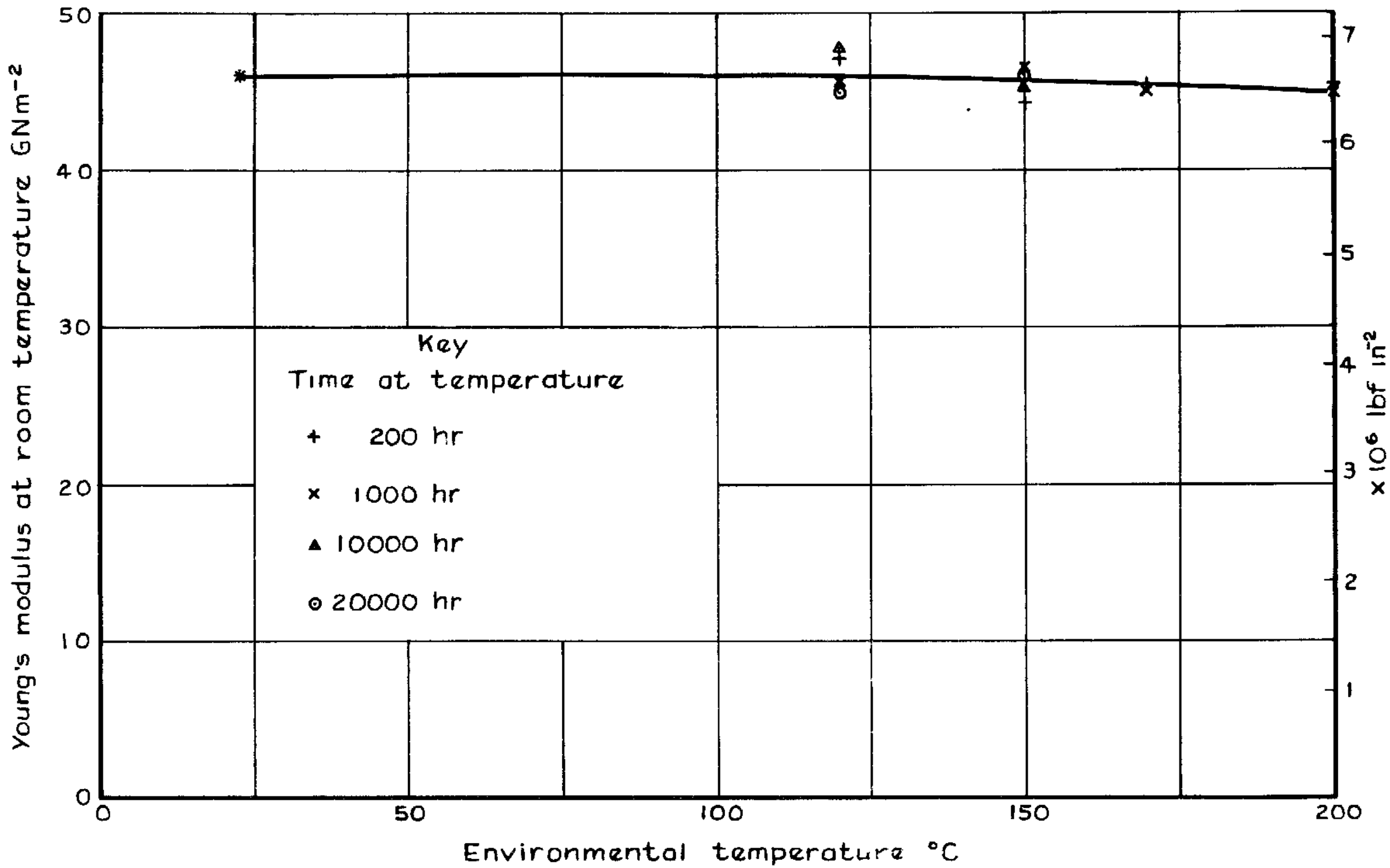


Fig. 13 Variation of Young's modulus at room temperature with long term environmental temperature

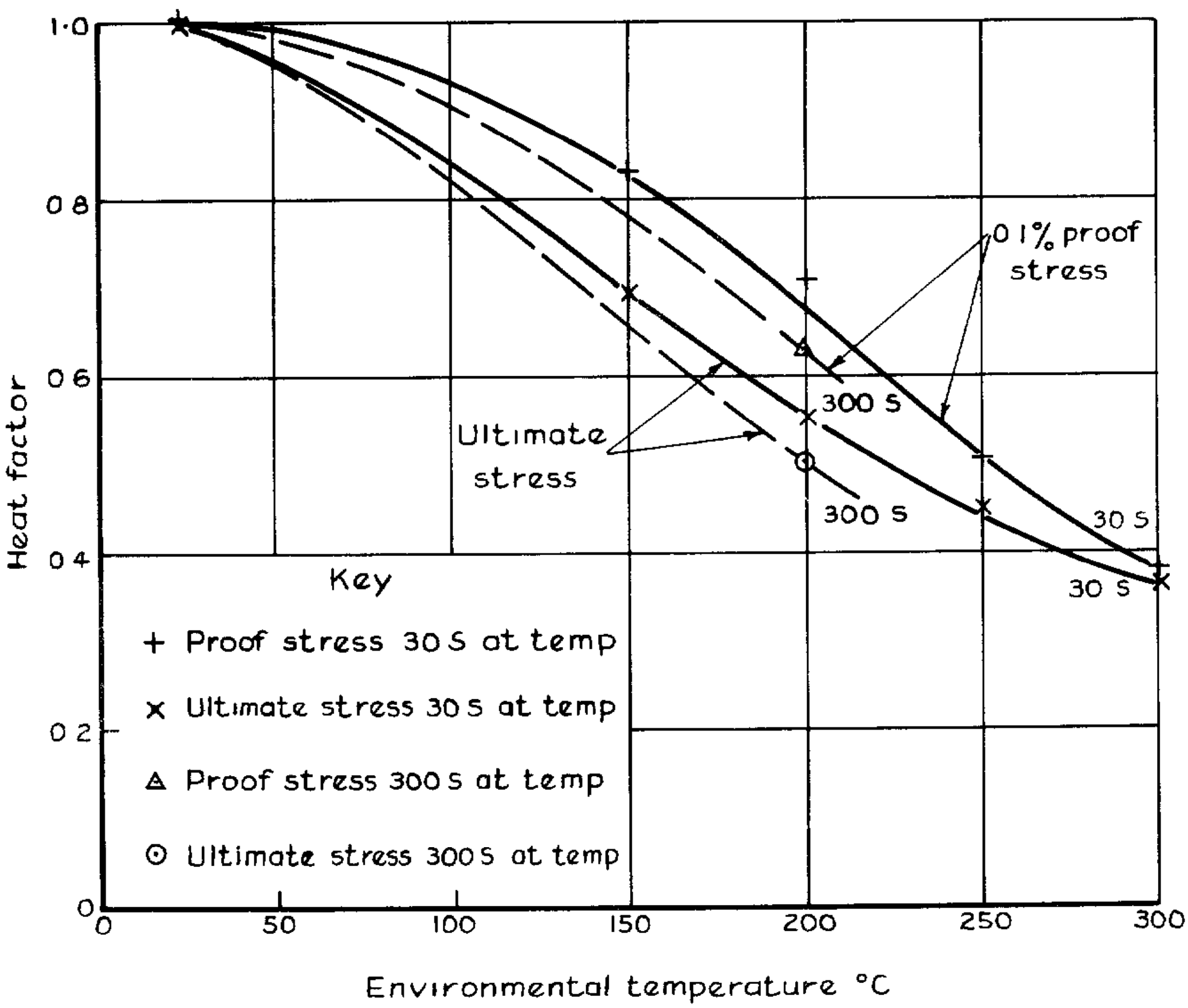


Fig.14 Variation of heat factors for 0·1% tensile proof stress and ultimate tensile stress with short term environmental temperature

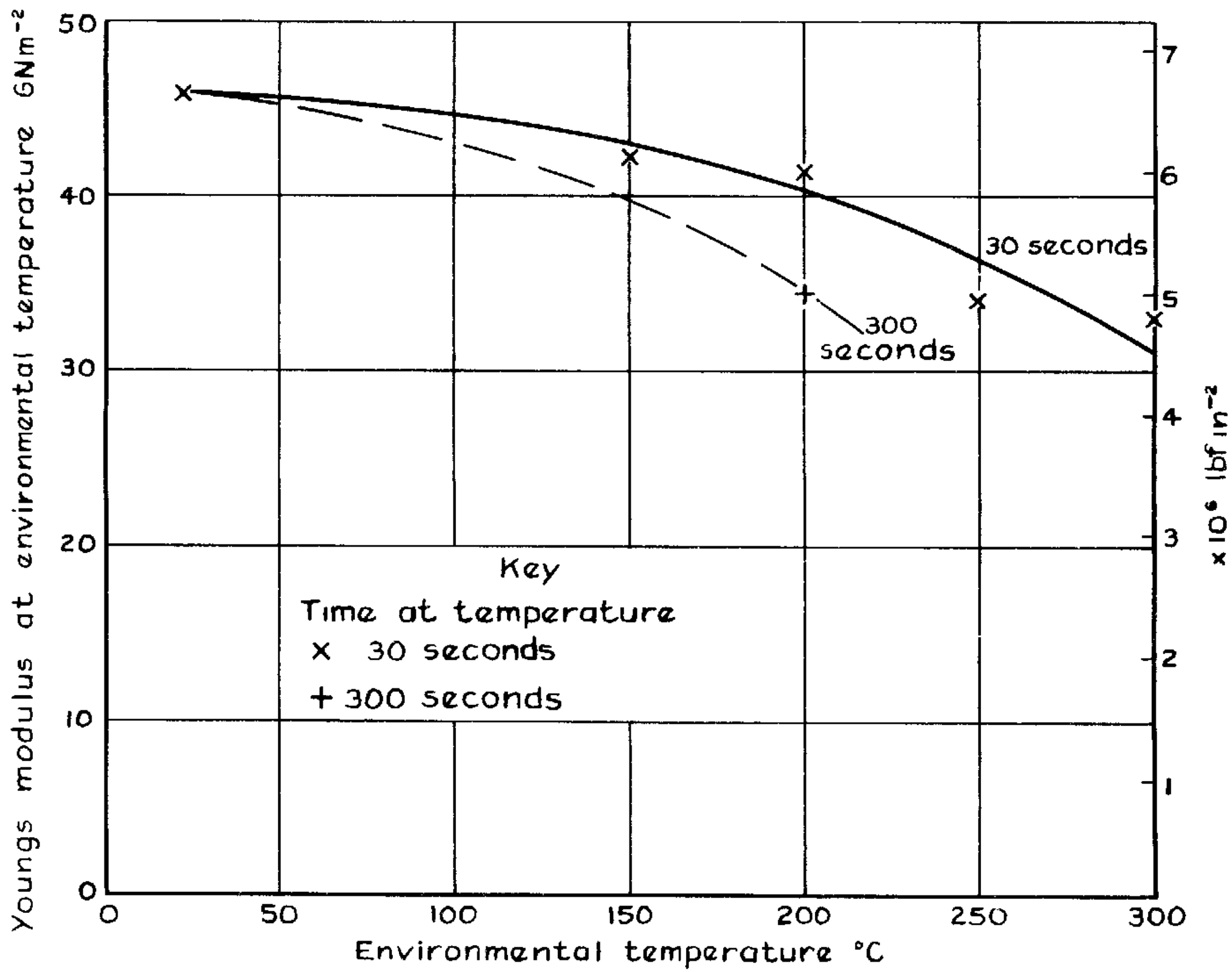


Fig 15 Variation of Young's modulus with short term environmental temperature

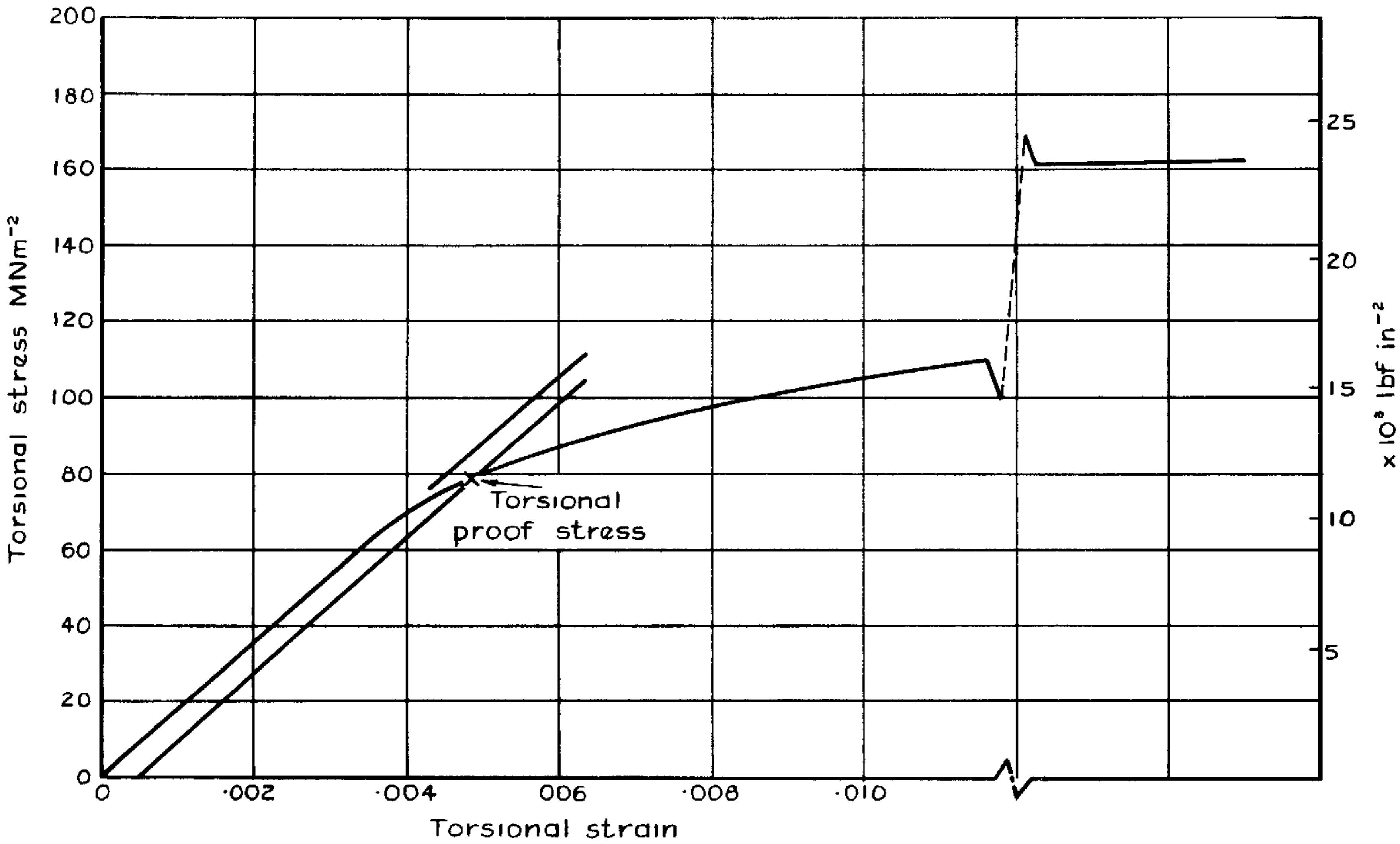


Fig.16 Typical torsional stress–strain curve

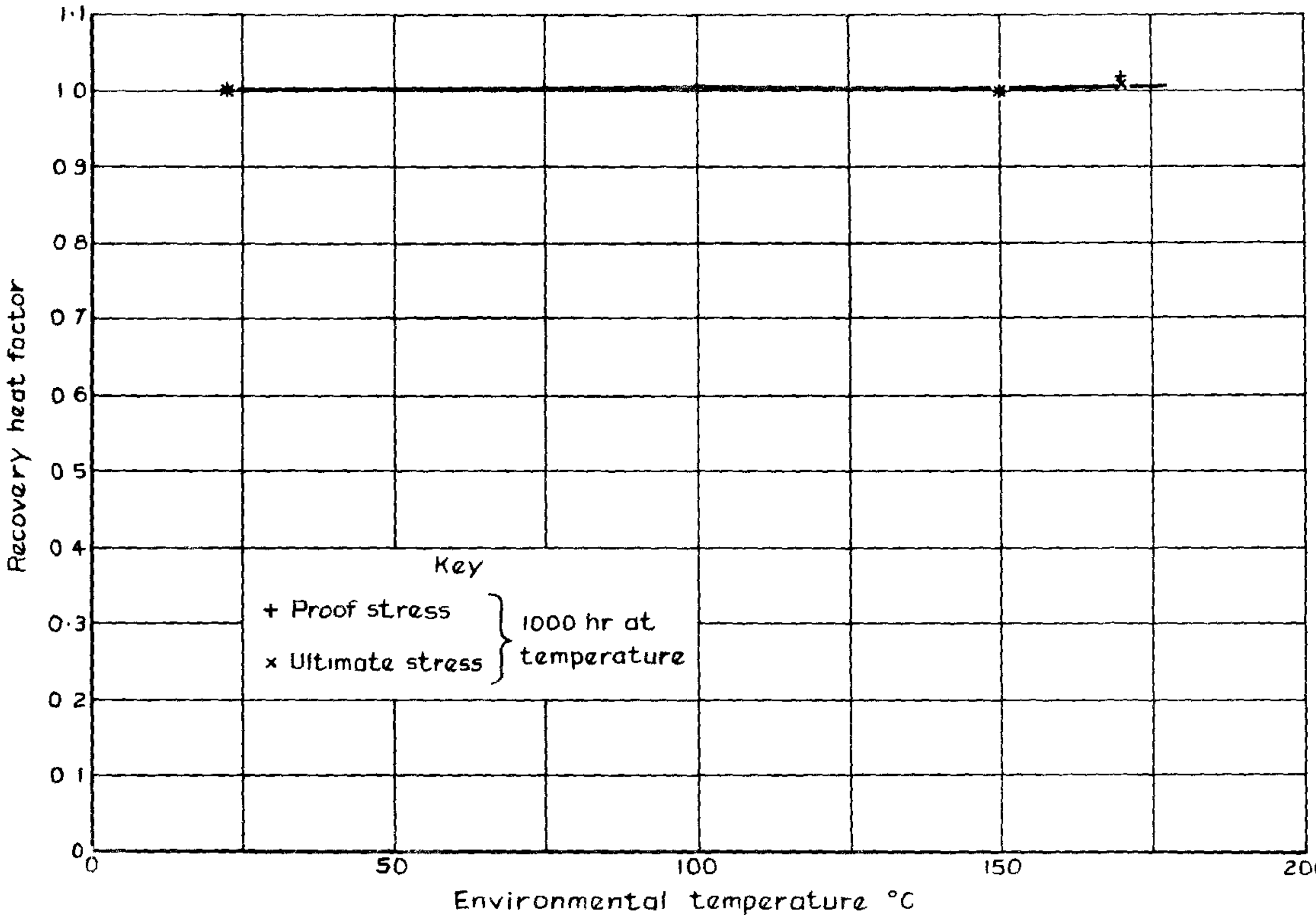


Fig.17 Variation of recovery heat factor for torsional proof and ultimate stress with long term environmental temperature

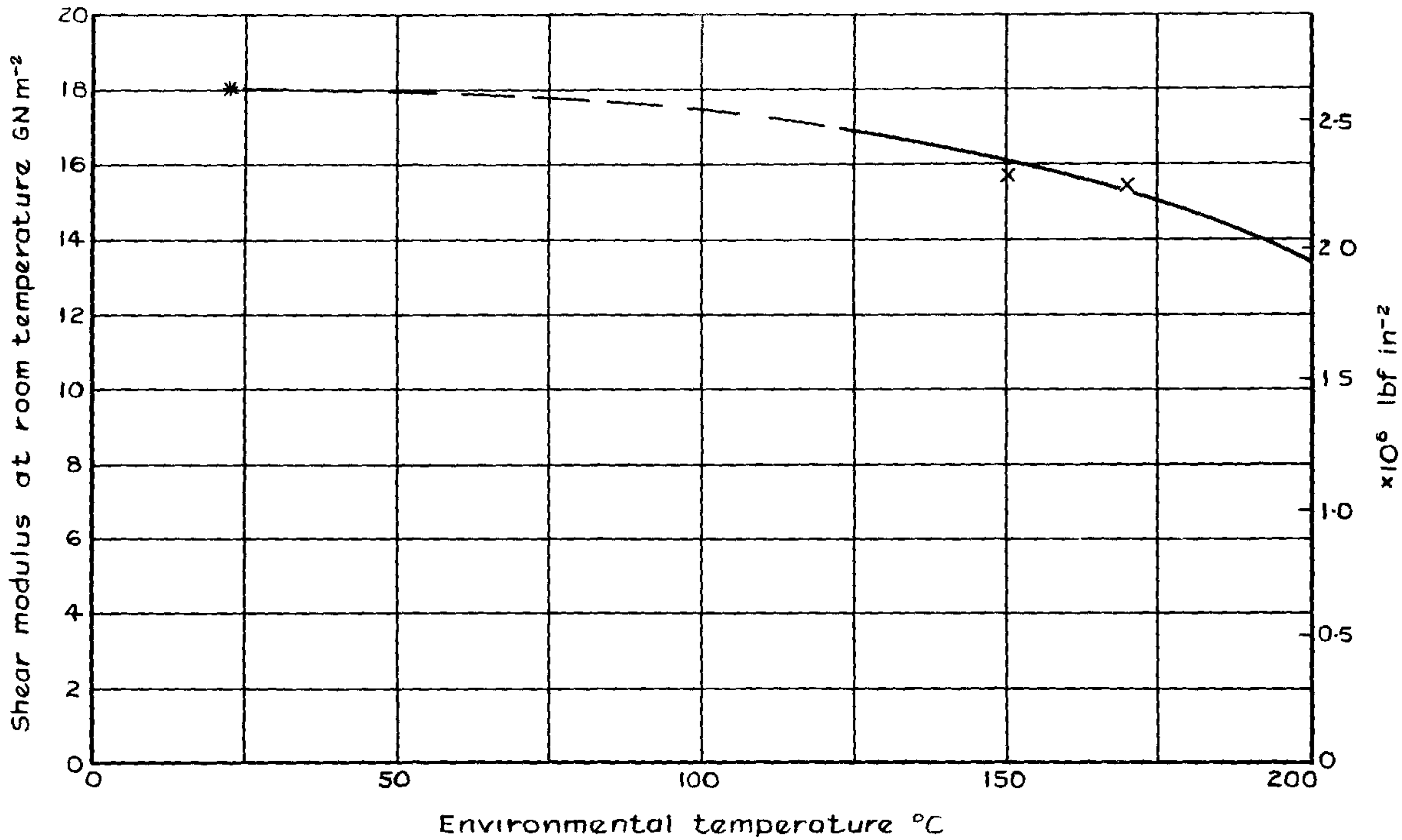


Fig.18 Variation of shear modulus with long term environmental temperature

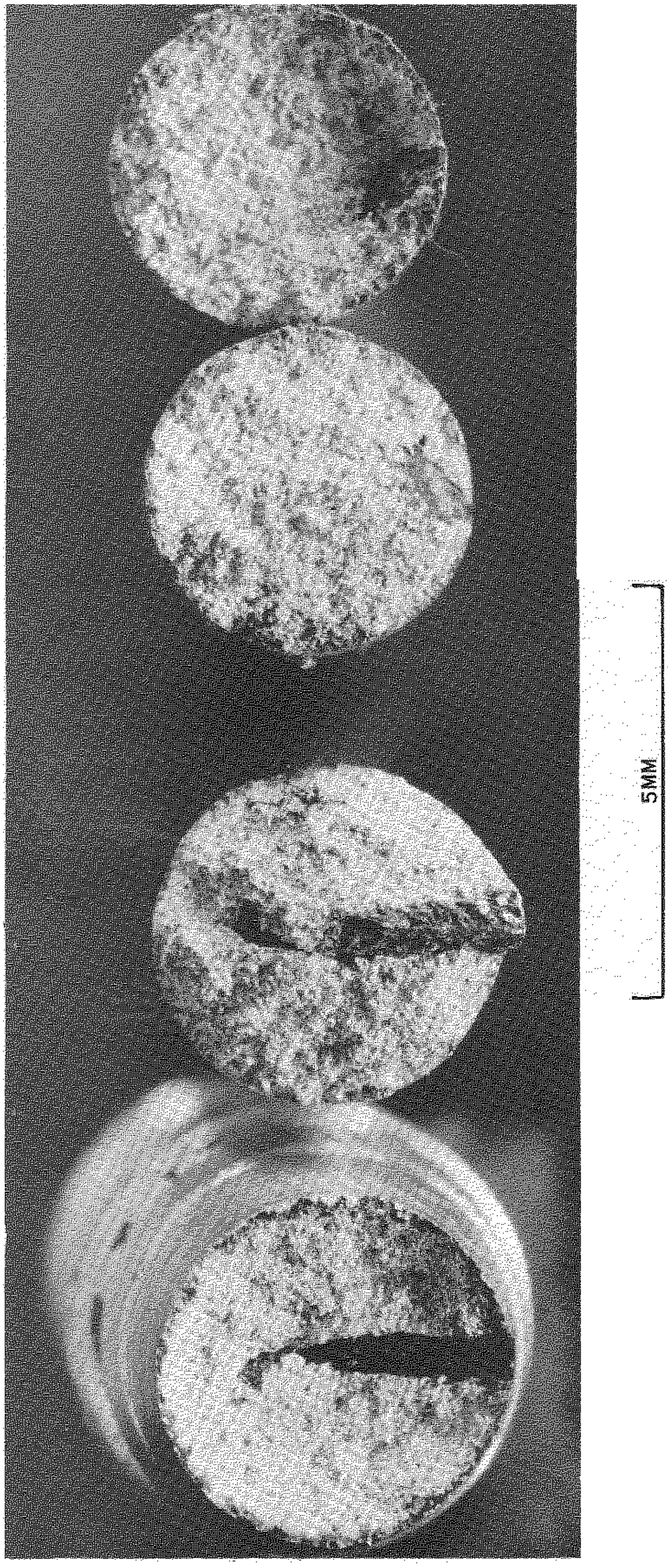


Fig.19. Typical inclusions on tensile fracture surfaces

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