THE STRESS RUPTURE PROPERTIES OF AUSTENITIC STEEL WELD METALS

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SUMMARY

Elevated temperature stress rupture data on Mo containing and Mo free austenitic weld metals have been collected from French, Dutch, German and UK sources and the results analysed. The stress rupture strength of Mo containing weld metal is significantly higher than that of Mo free weld metal. At 10,000h the rupture strength of Mo containing weld metal is higher than that of Type 316 steel whereas the Mo free weld metal is about 20% lower than that of Type 304 steel. Austenitic weld metal can give low stress rupture ductility values. It is concluded that there are insufficient data to permit reliable extrapolations to long times and it is recommended that long term tests are performed to overcome this situation.

This work was performed under CEC Study Contract RAP-024-81-UK in the frame of the Working Group Codes and Standards Activity 3 "Materials" of the Fast Reactor Coordinating Committee. Contributions have been made by M F Felsen CEA France, E te Heesen Interatom Germany and J Vrijen Neratoom Holland.

INTRODUCTION

In general design stresses at elevated temperature are based on the wrought material properties. Type 316 and Type 304 austenitic steels are of interest for fast breeder reactor primary circuits and considerable stress rupture data have been generated on these steels. Recognising this fact the Commission of European Communities (CEC) have previously placed two Study Contracts on Member States to collect and compare European stress rupture data on Type 316 steel(1,2). Although the wrought material properties are of obvious importance, when failures in structures do arise, they tend to occur in the weld metal region and it is therefore important to also evaluate the weld metal properties and to compare these with the corresponding wrought metal properties.

Since weld metal data are relatively sparse, the most productive approach is to collect and analyse the data on a collaborative basis. Such an approach has been adopted involving Commissariat A L'Energie Atomique (CEA) (France), Interatom (Germany), Neratoom (Holland) and UKAEA (UK) to collect stress rupture data on austenitic weld metals relevant to fast breeder reactors, and also to evaluate the information particularly in relation to the wrought material properties. This work has been performed under a CEC Study Contract (RAP-024-81-UK).

WELDING AND TESTING DETAILS

The welding and testing details are summarised in Table 1. Whereas the German data relate to Mo free weld metal (18% Cr - 11% Ni) the data from most of the other sources relate to Mo containing weld metal (18% Cr 12% Ni 2 Mo and 17% Cr-8% Ni-2% Mo). The specifications for the weld metals employed are given in Table 2 in terms of chemical composition. This table shows that the weld metal will usually contain ferrite; the actual measured values of the test samples were generally in the range 3-6%. All tests were performed on material which had not been heat treated after welding. Almost all the data relate to manual metal arc welds with a few tests on TIG and submerged arc welds. Whereas most welds were produced in the down-hand-position some of the specimens tested in France were taken from vertical welds involving a 'weaving' of the welding wire.

Regarding specimen orientation, in general three types of specimen were employed namely longitudinal, transverse (weld metal) and transverse (composite ie welded joint). The temperature range of testing was 500-750°C with most tests at 550-600°C. Full details of the welds, specimens and tests are given in References (3) to (6). All collaborating countries have provided information relating to time to rupture and also generally elongation and reduction of area values; the French and UK contributions also include information on the minimum creep rate.

RESULTS

a. Stress Rupture Strength

All the results in terms of strength are given in Figs 1 to 8; information relating to the direction of extraction of the specimen from the weld is given. An average curve has been drawn in by eye in each figure to allow comparisons later to be made. French data on 18/12/2 welds at 550, 580, 600 and 650°C are given in Figs 1 and 2. Testing times extend to 36000 h. Most relate to welding in the down-hand position; a few data points have had to be omitted from the figures since they did not fall within the categories specified. At 600°C and 650°C (Figure 2) the transverse strength is a little higher than the strength in the longitudinal direction.

German data on 18/11 welds at 500, 550, 600, 650 and 700°C are given in Figs 3, 4 and 5. Testing times extend to about 50,000 h. No significant differences could be detected between transverse (all weld) and transverse (composite) specimens. At 600°C the longitudinal specimens fall to the lower end of the scatter band but this is not the case at other temperatures where a comparison is possible.

The Dutch data at 550 and 600°C are given in Fig 6; test data extend to about 10,000 h duration. This information relates to welds in 18/12/2, 17/8/2 and 18/11 compositions. The results show the 18/11 weld to be weaker than the Mo containing weld, with no significant difference between the 18/12/2 and 17/8/2 welds. At 600°C there appears to be no effect of specimen orientation on strength.

The UK data obtained on 17/8/2 welds at 550, 575, 600 and 625°C are shown in Figs 7 and 8; test durations extend to 28,000 h. The sparcity of the data do not allow a strict evaluation of the directional properties, but the transverse strength appears to be at least as high as that in the longitudinal direction.

b. Minimum Creep Rate

Turning to the minimum creep rate, the only data available are from French and UK sources. Values have been obtained from both longitudinal and transverse specimens. The transverse samples tested are likely to have contained some parent metal; the creep rate may then depend on the relative proportions of weld metal and parent metal. The minimum creep rate values obtained on the Mo containing welds at 550, 575/580, 600, 625 and 650°C are given in Figs 9-11. At each temperature a curve has been drawn through the points by eye. In general, a straight line is obtained indicating that minimum creep rate α (stress)^n. As indicated in the figures the value of 'n' is found to be high, in the range 17-30; such high 'n' values mean that small changes in stress can result in large changes in creep rate. There is some indication that at lower stress levels a linear log stress versus log minimum creep rate relationship may not apply, the creep rate being higher than predicted. In Figs 9-11 it appears, particularly at 650°C that the creep rate in the transverse direction is lower than that in the longitudinal direction; it is not clear whether this difference is a true directional effect or brought about by the presence of parent metal in the transverse specimens.

c. Ductility

It is difficult to make a strict comparison of the ductility in terms of elongation because of the wide range of specimen sizes employed in the different countries. Instead, it is considered that the best comparison can be based on the reduction of area values measured. Even with this measure of ductility there is some uncertainty in relation to transverse welded joint specimens since the location of failure is not always known. For this reason the German data on welded joints has been omitted. It is known that the UK composite specimens failed in the weld region and this is also believed to be the case for the French and Dutch tests.

Reduction of area values for data from all contributing countries are plotted in terms of temperature (550, 575/580, 600, 625, 650 and 700°C) in Figs 12-14. A wide scatter in results is to be noted with maximum values in the region of 60-70% and minimum values of 1-10%. The results at each temperature show a tendency particularly at the higher temperatures for the ductility to fall with increasing testing time. There is also an indication that the 18/11 weld metal gives lower R of A values than the Mo containing weld metals; whereas minimum values of 1-2% have been observed with 18/11 weld metal no values lower than 5% have been noted with the Mo containing weld metals. Considering the R of A information at <10% the German data includes 11 data points out of a total of 72 (∿15%), although many of these were observed at 700°C a temperature not employed in the other countries. Four of the French data points out 158 (∿3%) and 4 out of 57 (∿7%) of the UK data points gave R of A values <10%. These results suggest that the 17/8/2 weld metal is less ductile than the 18/12/2 weld metal; it should be noted however that in a UK comparison which also included data from the USA and Japan it was concluded that the 18/12/2 ductilities tended to be lower than the 17/8/2 ductilities(7).

DISCUSSION

A comparison of the average strength behaviour from data from the different countries based on Figs 1-8 at times of 1000 h and 10,000 h is given in Figs 15 and 16 respectively. These figures clearly show the superior strength of the Mo containing weld metals over the Mo free weld metal by as much as 50%. They also show that there is little difference between the 18/12/2 and 17/8/2 weld metals and therefore for analytical purposes the data from these weld metals can be considered collectively. It is also worth noting that the French data fall into a consistent pattern over the complete temperature range studied even though the points at 580°C were derived from specimens taken from vertically welded joints; these results therefore indicate that welding position has no significant effect on the rupture strength.

From Figs 15 and 16 it is clear that under certain weld metal/temperature situations data from the different countries can be combined into common data sets. The collective data obtained for Mo containing weld metals (at 550 and 600°C) and for 18/11 weld metal (at 550°C) are shown in Figs 17 and 18 together with scatter bands encompassing the data. Fig 17 shows good agreement between the French, Dutch and UK data at both temperatures; the scatter bands are in fact defined by the French data, the Dutch and UK data falling towards the centre of the scatter bands.

The weld metal scatter bands based on Figs 1-8, 17 and 18 in terms of Mo containing and Mo free compositions at times of 1000 h and 10,000 h are shown in Figs 19 and 20. All the results are reasonably self consistent and again confirm the superiority of the Mo containing weld metal particularly at the longer time of 10,000 h.

In the design of welded components the allowable stress at temperatures in the creep range is often based on the stress rupture strength of the wrought material. It is therefore important to know how the weld metal strength compares with that of the wrought material. In the case of the Mo free composition this weld metal is usually used with 18 Cr/11 Ni steel designated Type 304 steel, the German equivalent being 1.4948(8). The average stress rupture values for steel 1.4948(8) are reproduced in Figs 21 and 22 for rupture times of 1000 h and 10,000 h respectively, together with the scatter bands for the weld metal. At both times the figures indicate that the average strength for the wrought steel falls near the top bound of the scatter band for the weld metal. These figures indicate that on average the Mo free weld metal strength is about 20% lower than that of the corresponding wrought material. This situation has already been recognised, and in the VdTUV document weld metal factors are specified to allow for the fact that the weld metal is weaker than the parent metal. These factors vary from a value of 0.63 for 700°C and 200,000h to 0.97 for 500°C and 1000h.

In the case of the Mo containing weld metal, this is usually used in conjunction with Type 316 wrought steel. Wide variations have been noted in the stength of Type 316 steel on the basis of national data available in France, Germany, Italy and the UK(2). It is therefore difficult to draw comparisons between the weld metal and wrought metal strengths. Nevertheless 1000 h and 10,000 h scatter bands have been derived for the <u>average</u> values from data from these four countries as assessed by a Larson-Miller parametric approach with optimised constant(2). The <u>average</u> values thus obtained for the wrought material are compared with the full scatter band for the weld metal in Figs 21 and 22. At 1000 h the wrought material is generally stronger than the weld metal but at

10,000 h the situation is reversed. This behaviour implies that the slope of the stress to rupture versus time to rupture plot for the weld metal is less than for the wrought metal and hence beyond 10,000 h the weld metal will continue to be stronger than the wrought material. Thus at lower stresses and longer times relevant to design the weld metal will be stronger, and the design of welded components based on wrought metal strength should be safe.

Although the initial intention was to extrapolate the data to times of up to 250,000 h it is concluded that there are insufficient long term data to perform such an extrapolation in a reliable manner. Since for design purposes such information is necessary it is recommended from this evaluation that long term experiments should be mounted to provide appropriate data.

It should also be noted that the information in this document relates to manual metal arc welds. If other types of weld eg submerged arc, tungsten inert gas are to be employed in the creep range it will be necessary to obtain appropriate stress rupture data on weld metal produced by these other methods.

CONCLUSIONS

1. The stress rupture strength of Mo containing weld metal is significantly greater than that of Mo free weld metal.
2. There is no significant difference in rupture strength between 18 Cr/12 Ni/2 Mo and 17 Cr/8 Ni/2 Mo weld metal.
3. The rupture strength of Mo free weld metal is of the order of 20% below that of 18 Cr/11 Ni steel; the precise difference depends on the time and temperature.
4. At 10,000 h the rupture strength of the Mo containing weld metal is higher than that of Type 316 steel; this behaviour is expected to extend to longer times.
5. Austenitic weld metals can give relatively low ductility values. There is a tendency for the Mo free weld metal to give lower values than the Mo containing weld metals.
6. There are insufficient long term data to provide reliable extrapolations to the lifetime of components.

RECOMMENDATION

It is recommended that long term stress rupture tests are mounted on austenitic weld metals to provide data that can be reliably extrapolated to the service life of components.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions made by Miss Felsen (CEA), Mr te Heesen (Interatom) and Dr Vrijen (Neratoom).

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2. BRUNORI et al. Comparison among creep rupture strength extrapolation methods with application to data for AISI 316 from Italy, France, UK and FRG. Nira Report T-ZA-5828.

3. FELSEN M F. CEC Study Contract on stress rupture properties of austenitic steel welds. CEA Report DT 13-01 (1981).

4. KOPPEN. Interatom data contribution to CEC Study Contract on stress rupture properties of austenitic welds. Interatom Report 55.04997.2 (1981).

5. NIEUWLAND H C D. Neratom data contribution to CEC Study Contract on stress rupture properties of austenitic welds. December 1981.

6. WOOD D S. UKAEA data file on stress rupture properties of austenitic weld metals. January 1982.

7. HORTON C A P and THOMAS R G. Private communication.

8. V d T U V Werkstaffblatt Hochwarmfester austenistischer Walz und schmiedestahl
x 6 CrNi 1811 (W-Nr.1.4948) 313 1.79.

Table 1 - Welding and Testing Details

	French Data	German Data	Dutch Data	UK Data
Nominal chemical composition	18Cr-12Ni-2Mo	18Cr-11Ni	18Cr-12Ni-2Mo 17Cr- 8Ni-2Mo 18Cr-11Ni	17Cr-8Ni-2Mo
Welding process	Manual metal arc	Manual metal arc (1)	Manual metal arc; TIG	Manual metal arc
Welding position	Down-hand and vertical	Details not given	Details not given	Down-hand
Thickness of weld deposit (mm)	10-35 (2)	12-100	20-22	20-31
Heat treatment after welding	None	None	None	None
Number of batches	13	16 (1)	7	2
Temperature range of tests (°C)	550-650	500-750	550-600	550-625
Number of data points	158	200	27	57
Specimen orientation	Long Transverse (all weld)	Long Transverse (all weld) Transverse (composite) (3)	Long Transverse (composite)	Long Transverse (composite)

(1) Includes one batch of TIG and two batches of submerged arc.

(2) Includes possibly larger weld metal blocks.

(3) Includes some specimens taken in the perpendicular direction.

TABLE 2

SPECIFICATIONS FOR WELD METALS

	Chemical Composition Wt (%)								Ferrite Number
	C	Cr	Ni	Mo	Mn	Si	S	P	
French 18-12-2	0.045-0.065	18.0-19.0	11.0-13.0	1.8-2.2	1.0-2.0	0.40-0.80	< 0.025	< 0.030	< 7
German(1) (2) 18-11	0.03-0.07	17.5-19.5	9.0-11.0	≤ 0.050	≤ 2.0	≤ 0.75	≤ 0.015	≤ 0.025	≤ 7[+]
UK(3) 17-8-2	0.06-0.10	16.5-18.5	8.0-9.5	1.5-2.5	0.5-2.5	0.8 max	0.03 max	0.03 max	(4)

(1) Includes B ≤ 0.0015.

(2) Also applicable to Dutch 18-11 weld metal.

(3) BS 2926 1970 17-8-2.

(4) Target ferrite number 4-8% for fast reactor applications.

[+] The extent of delta ferrite should be insufficient to produce a continuous network.

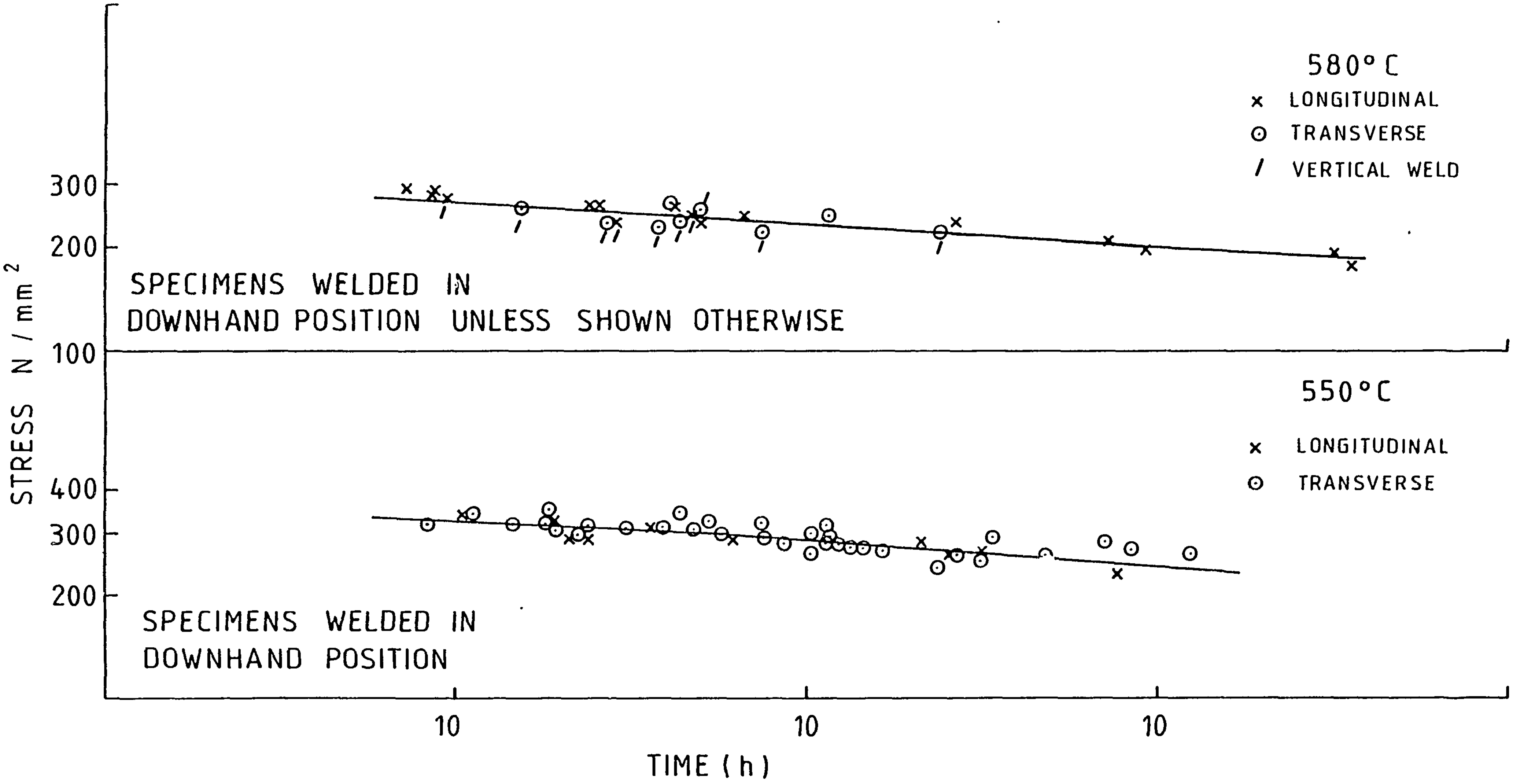

FIG. 1 FRENCH DATA : STRESS RUPTURE STRENGTH AT 550° AND 580°C

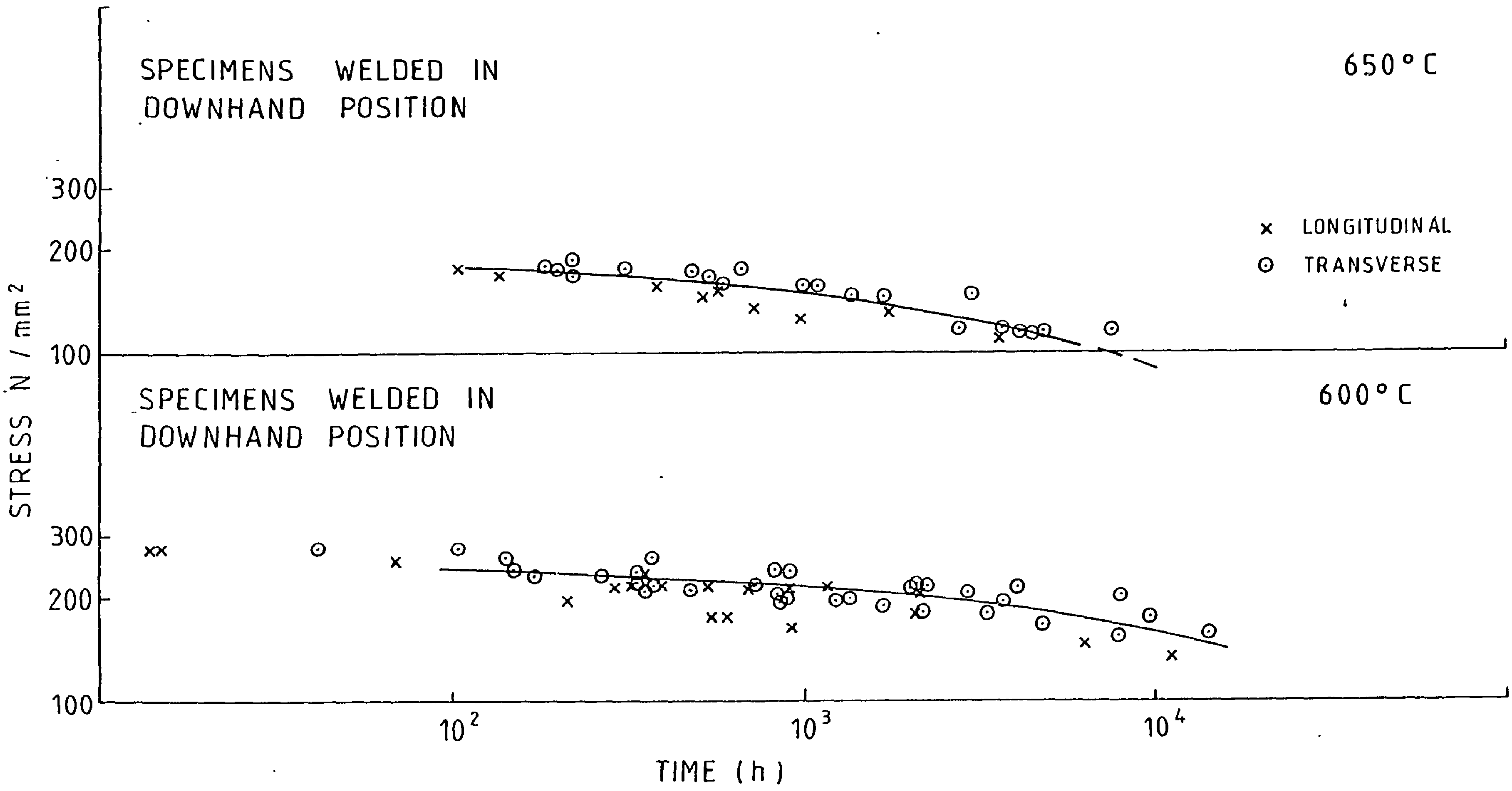

FIG. 2 FRENCH DATA : STRESS RUPTURE STRENGTH AT 600° AND 650°C

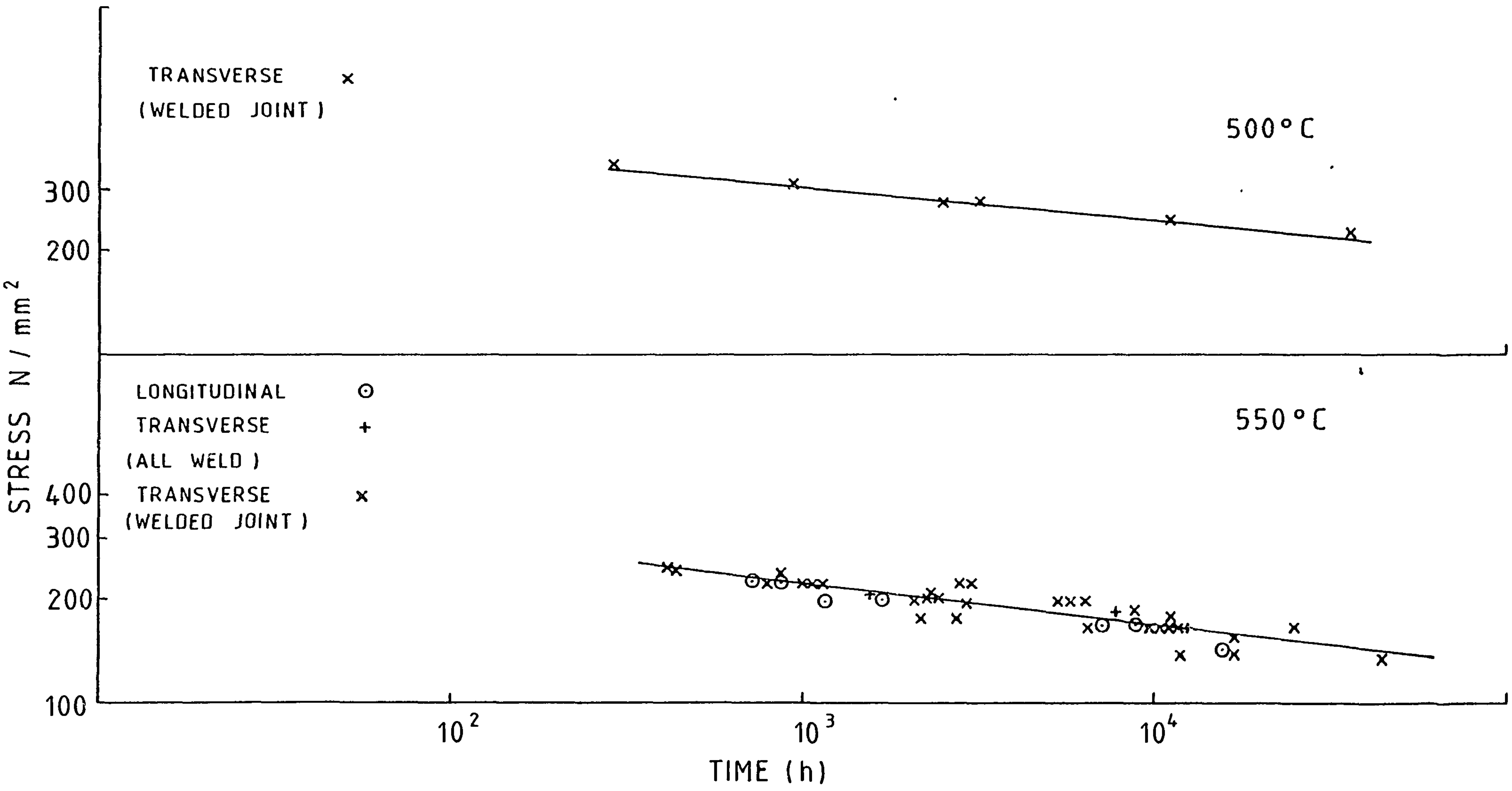

FIG. 3 GERMAN DATA : STRESS RUPTURE STRENGTH AT 500° AND 550°C

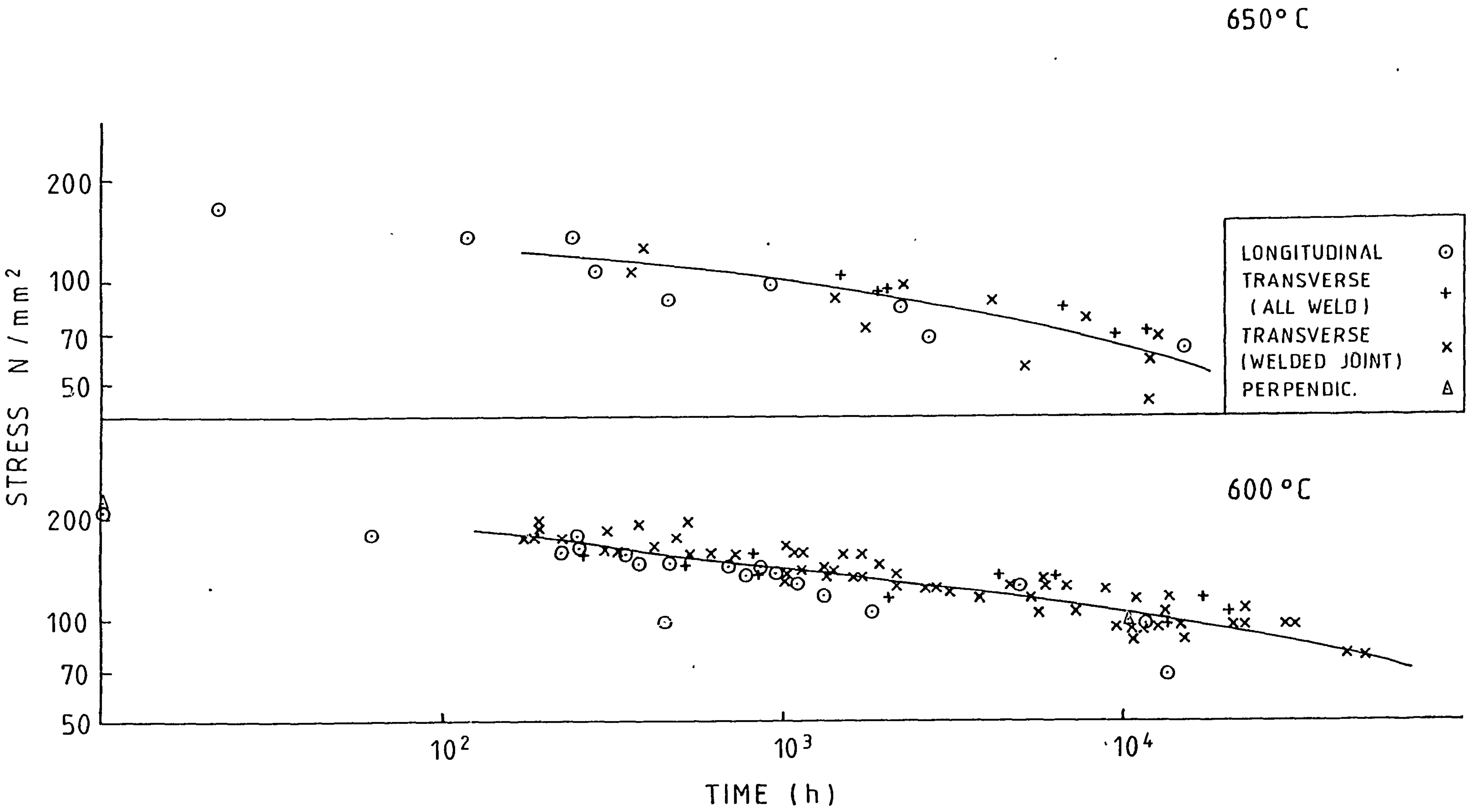

FIG. 4 GERMAN DATA : STRESS RUPTURE STRENGTH AT 600° AND 650 °C

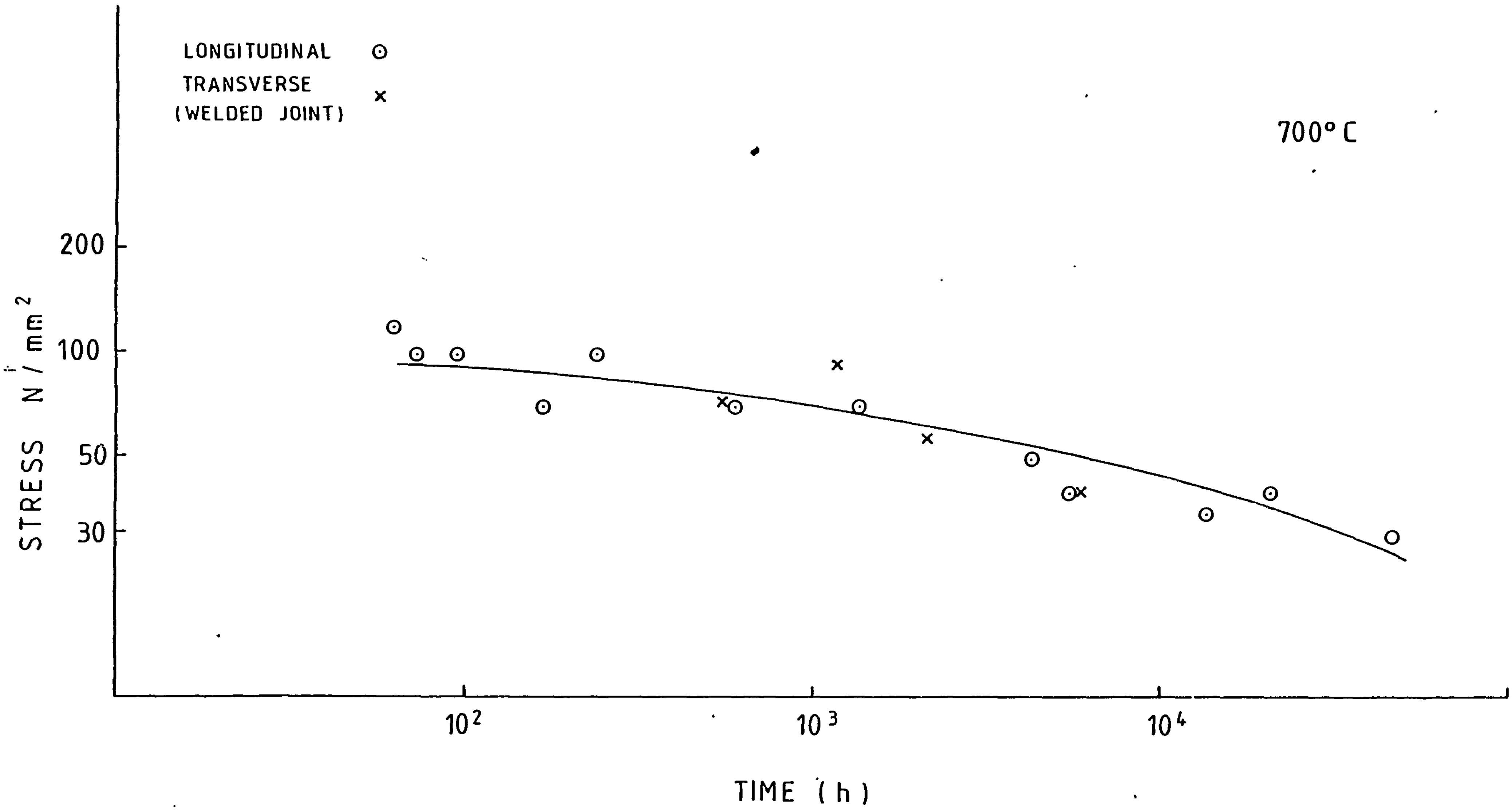

FIG. 5 GERMAN DATA : STRESS RUPTURE STRENGTH AT 700° C

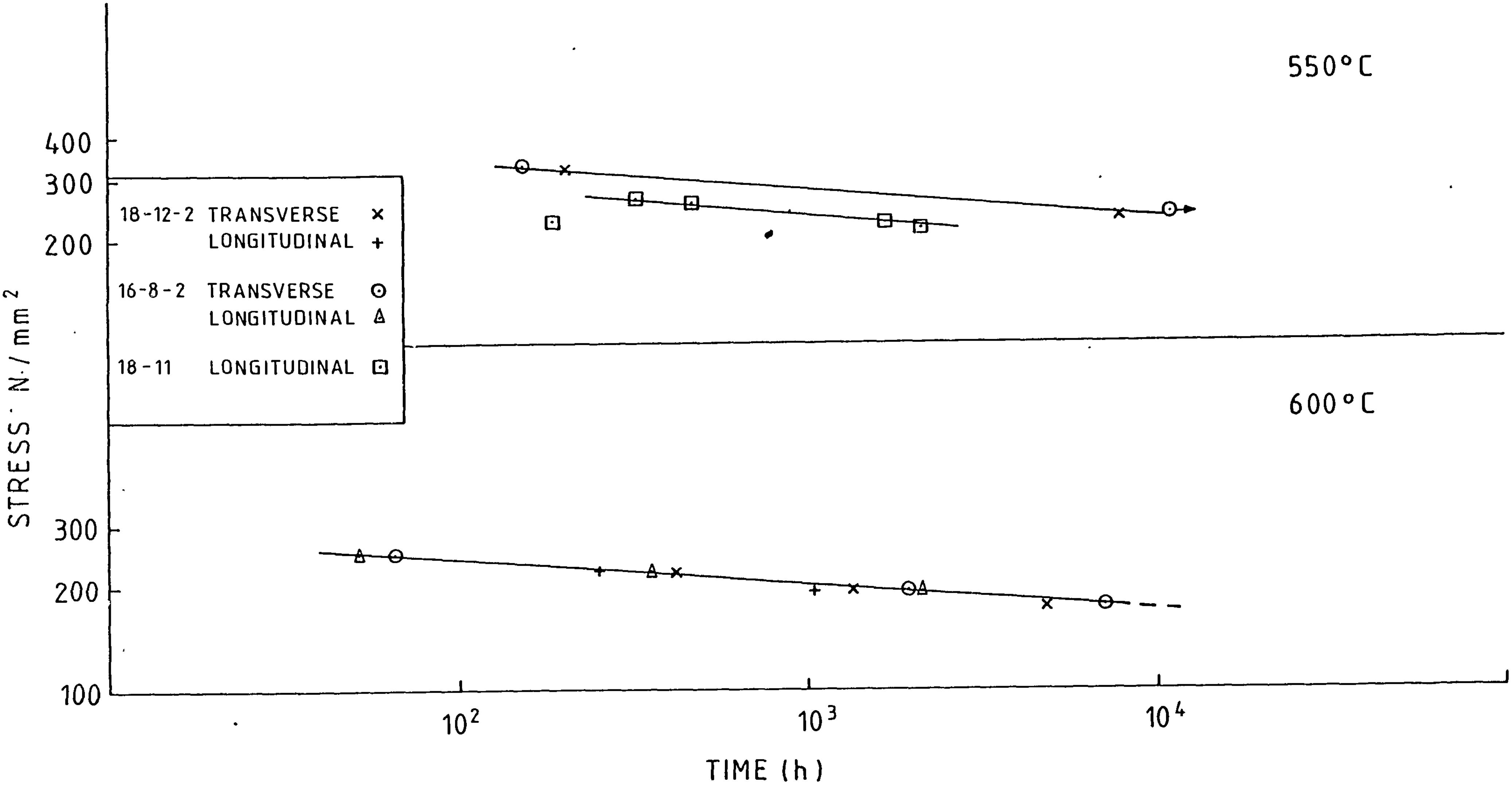

FIG. 6 DUTCH DATA : STRESS RUPTURE STRENGTH AT 550° AND 600°C

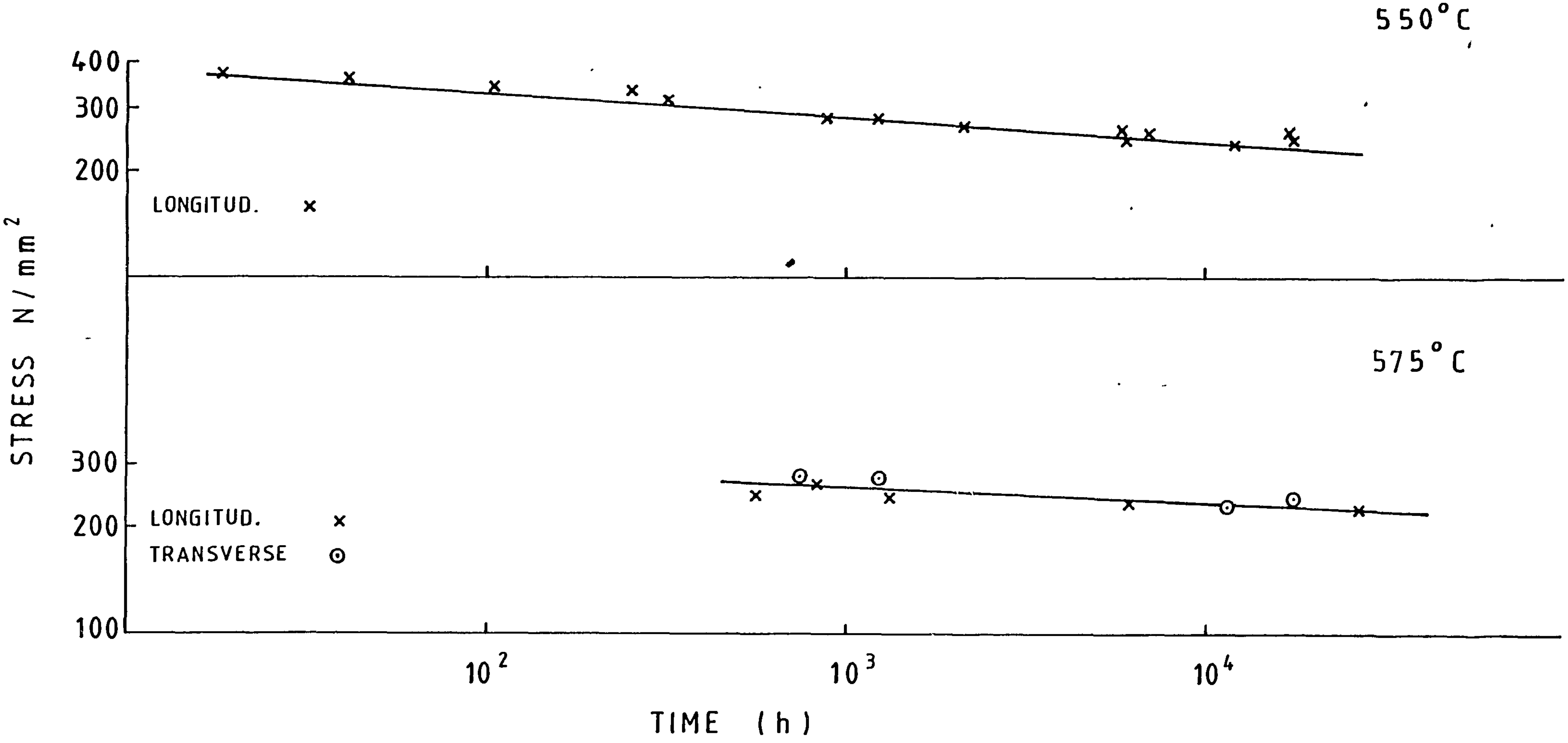

FIG. 7 UK DATA : STRESS RUPTURE STRENGTH AT 550° AND 575°C

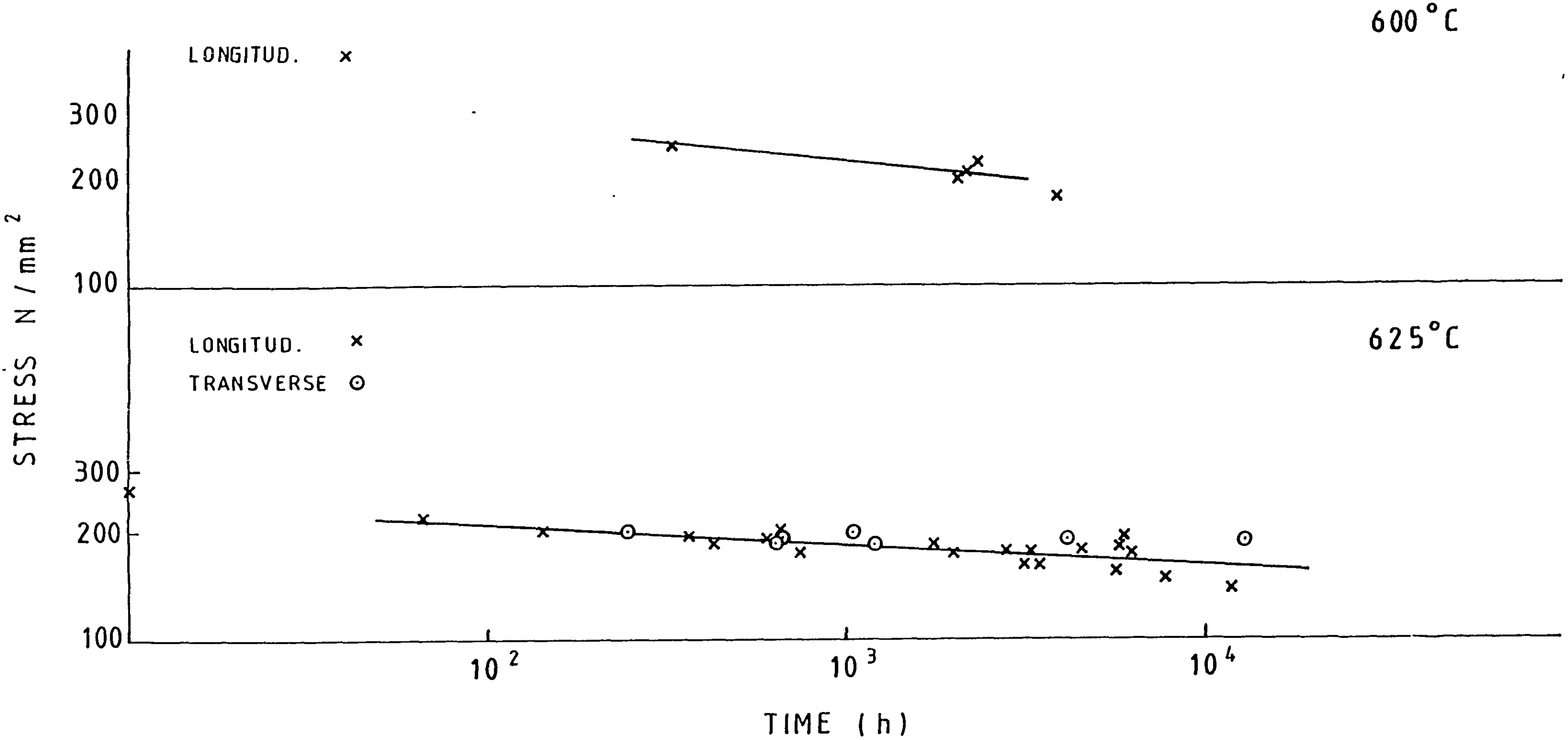

FIG. 8 UK DATA : STRESS RUPTURE STRENGTH AT 600° AND 625°C

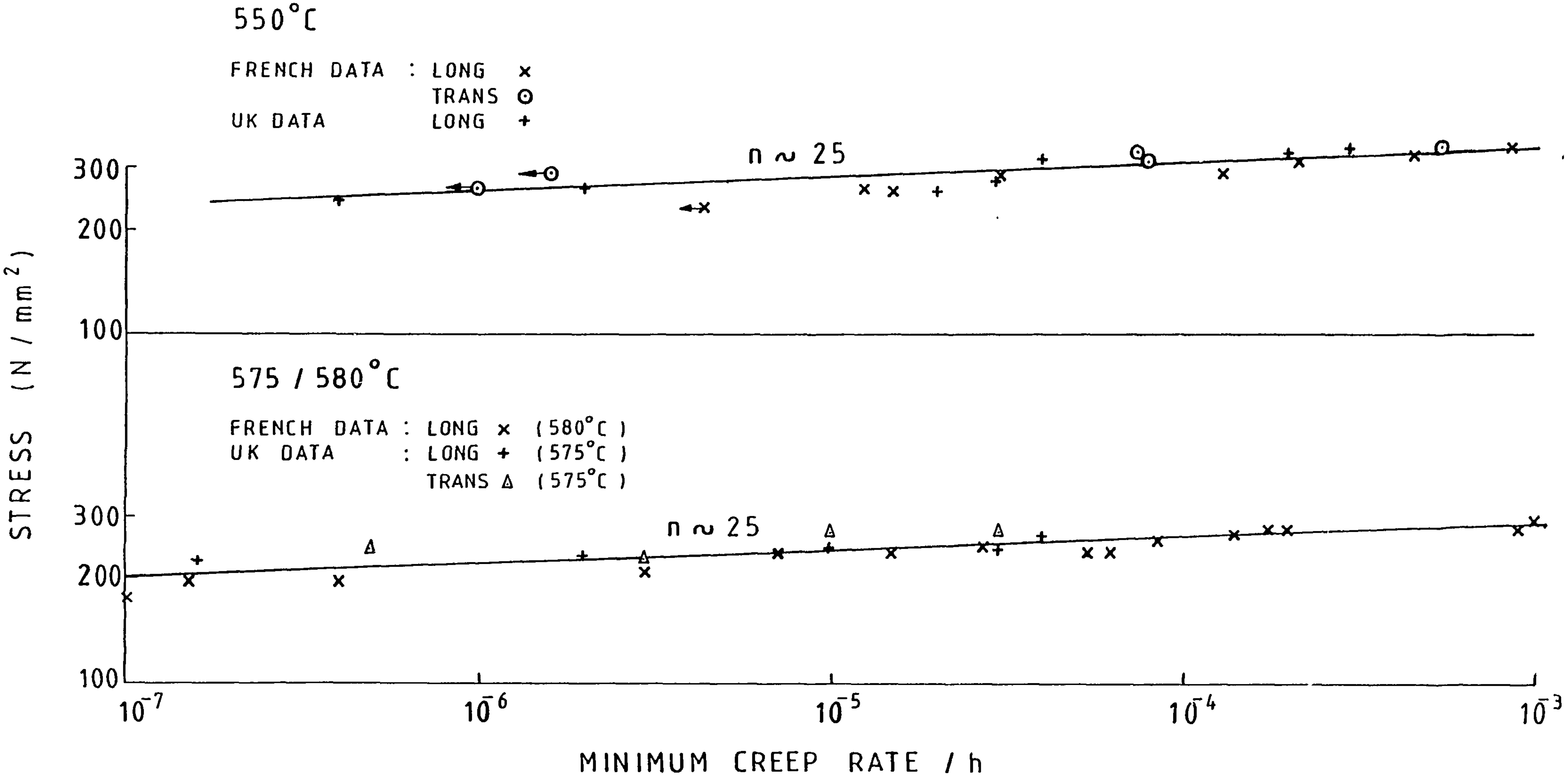

FIG. 9 MINIMUM CREEP RATE AT 550° AND 575°/580°C

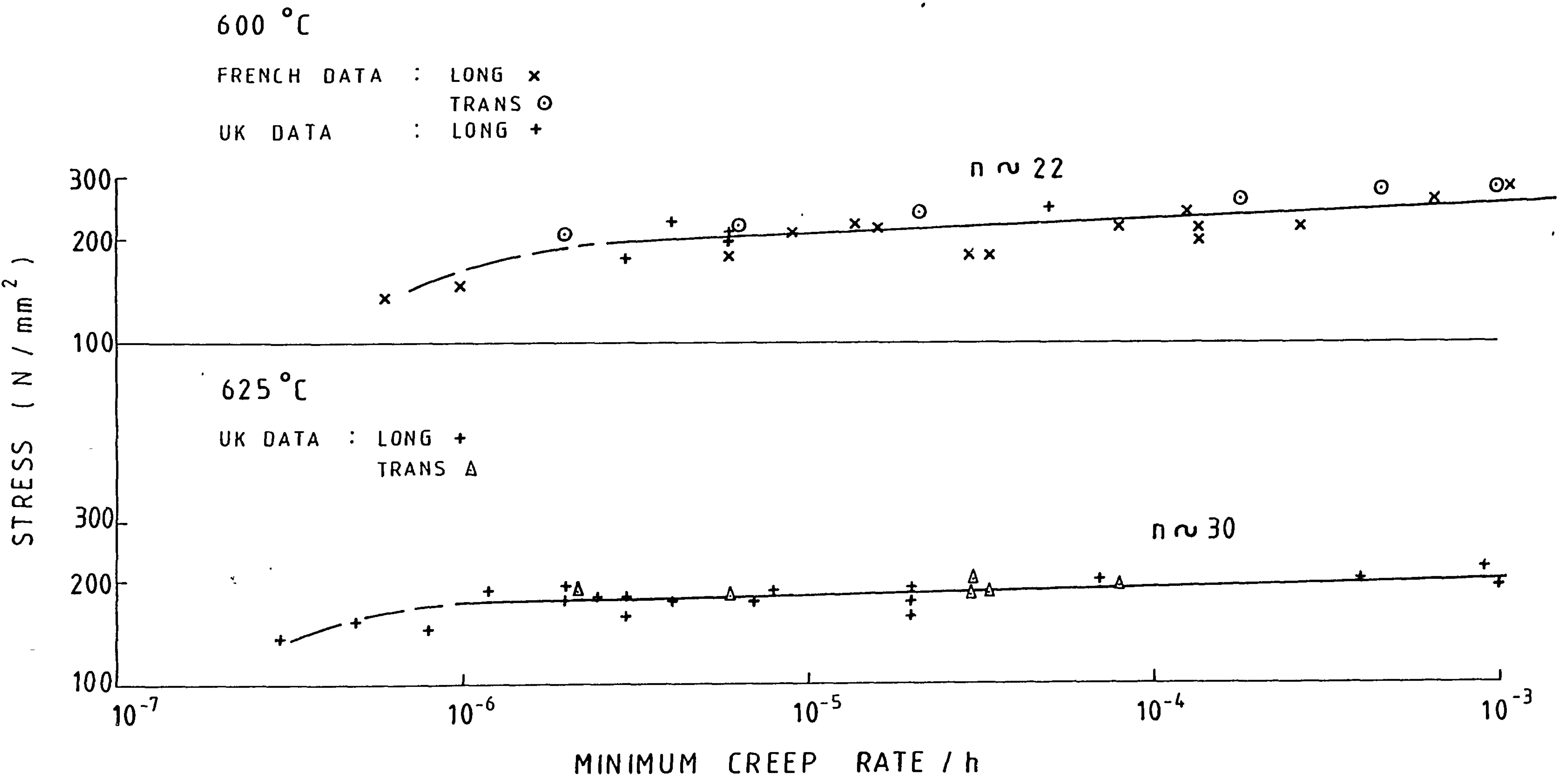

FIG. 10 MINIMUM CREEP RATE AT 600° AND 625°C

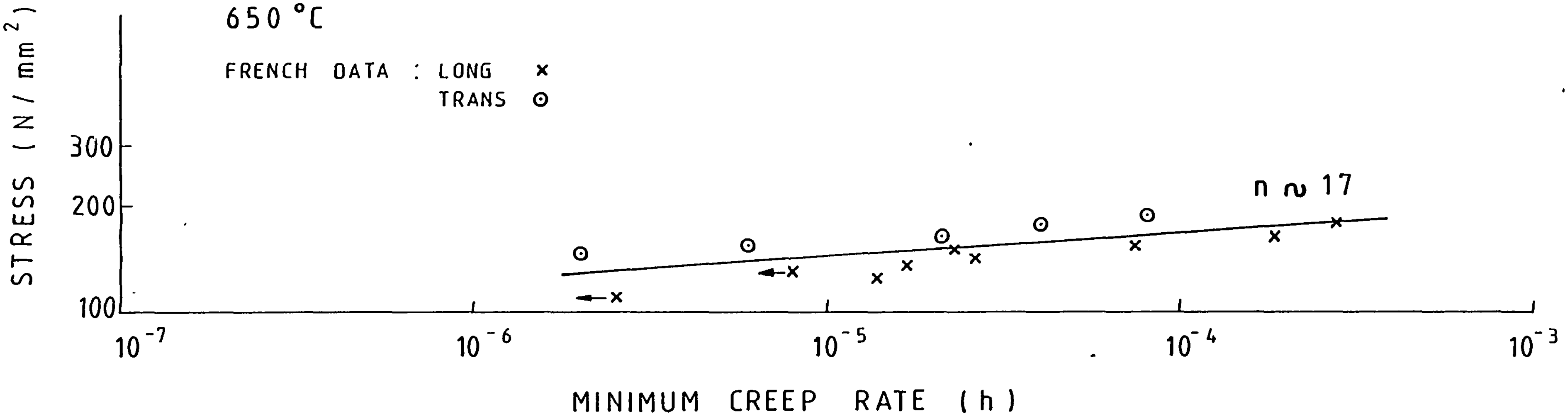

FIG. 11 MINIMUM CREEP RATE AT 650°C

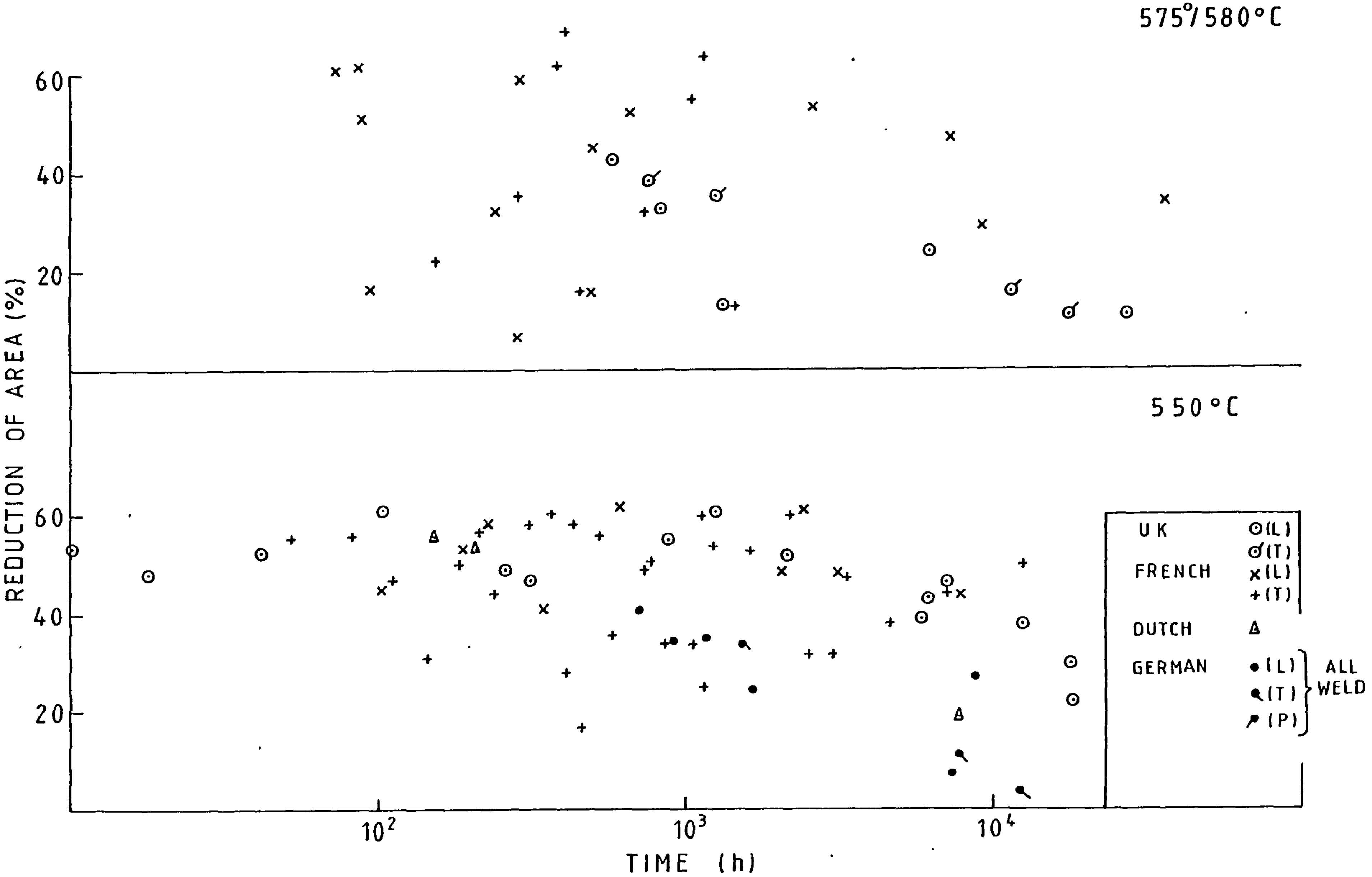

FIG. 12 ALL DATA : RUPTURE DUCTILITY AT 550° AND 575°/ 580° C

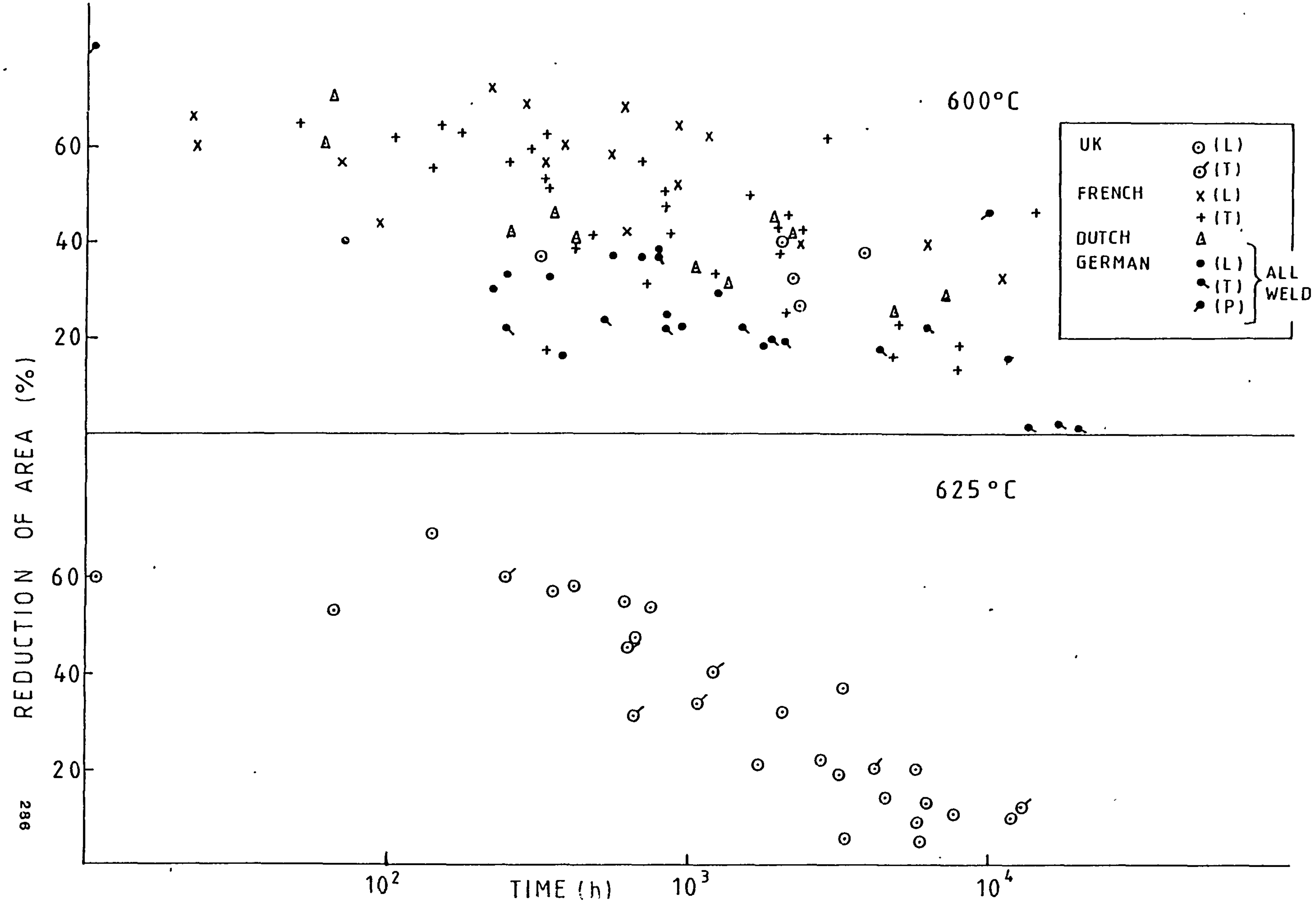

FIG. 13 ALL DATA: RUPTURE DUCTILITY AT 600° AND 625° C

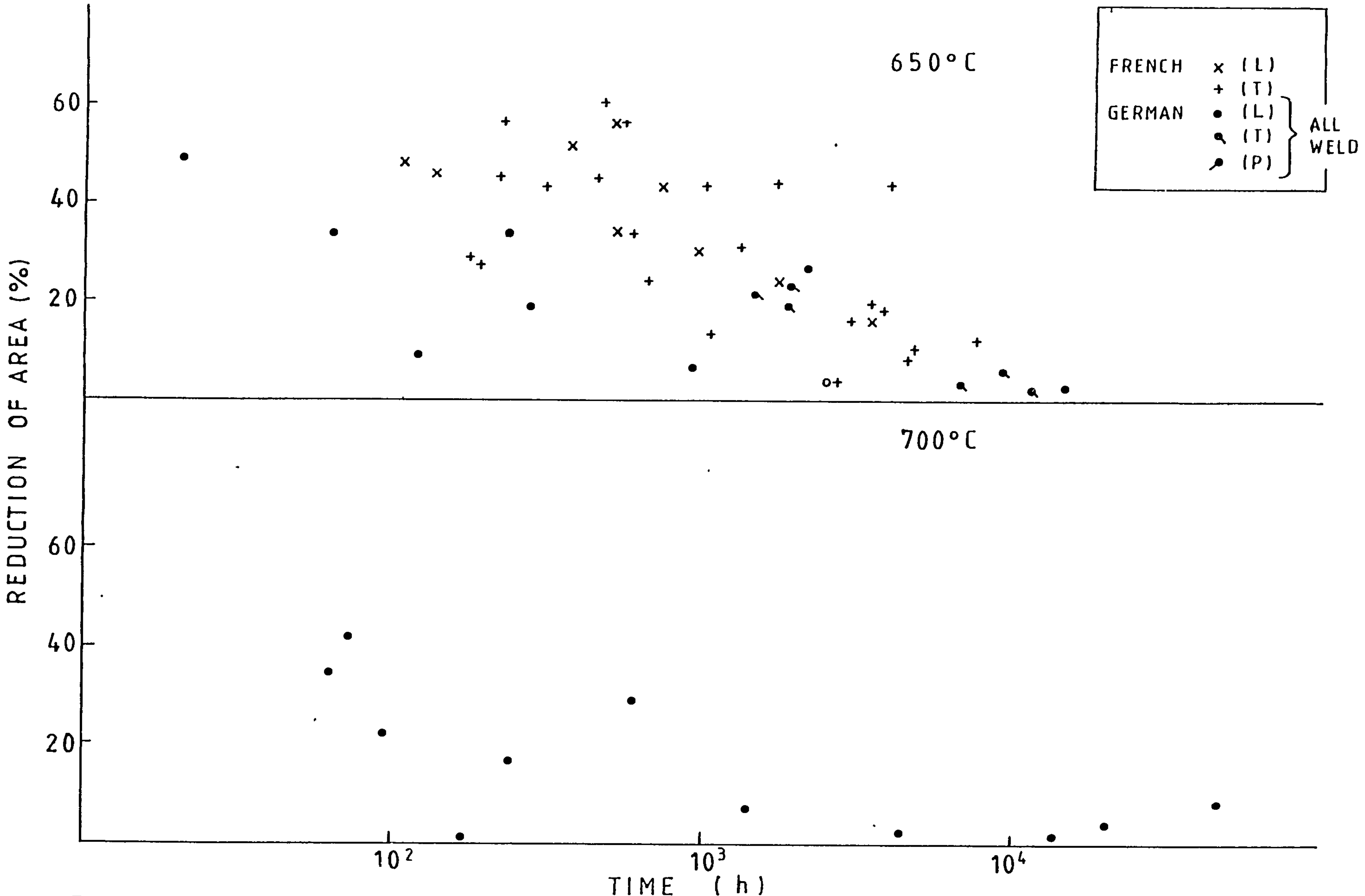

FIG. 14 ALL DATA: RUPTURE DUCTILITY AT 650° AND 700°C

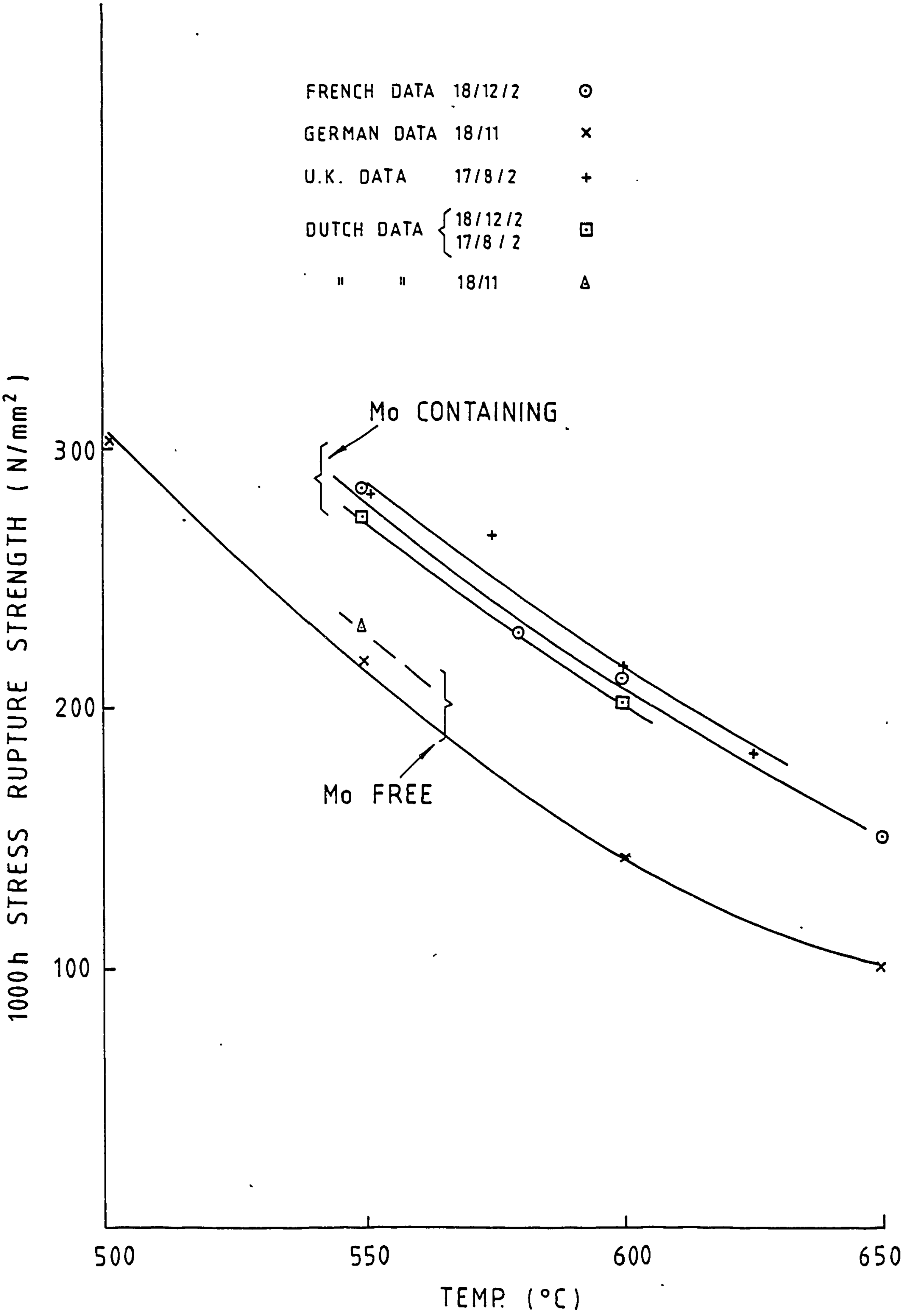

FIG.15 1000h WELD METAL STRESS RUPTURE STRENGTH (AVERAGE BEHAVIOUR)

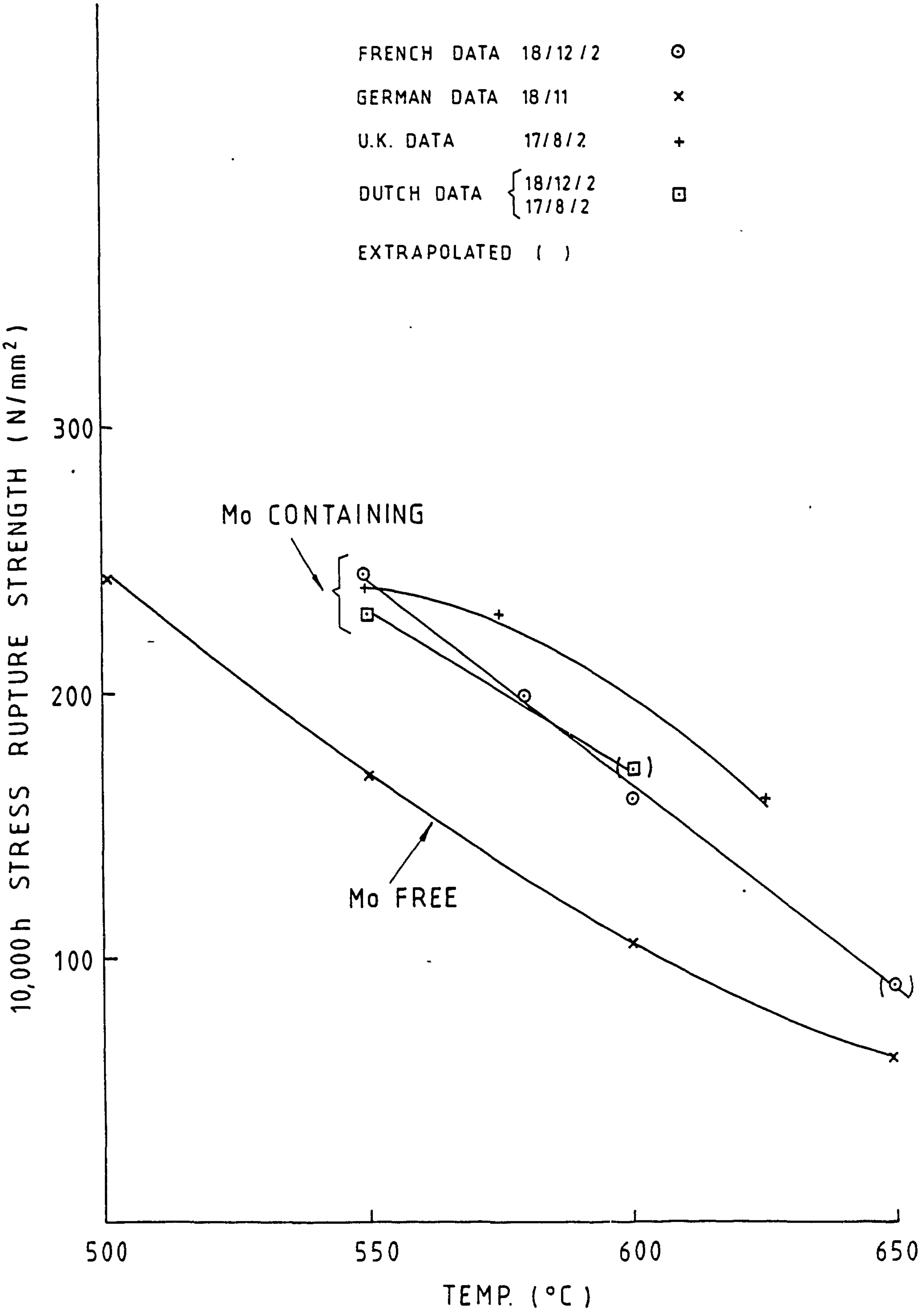

FIG. 16 10,000h WELD METAL STRESS RUPTURE STRENGTH (AVERAGE BEHAVIOUR)

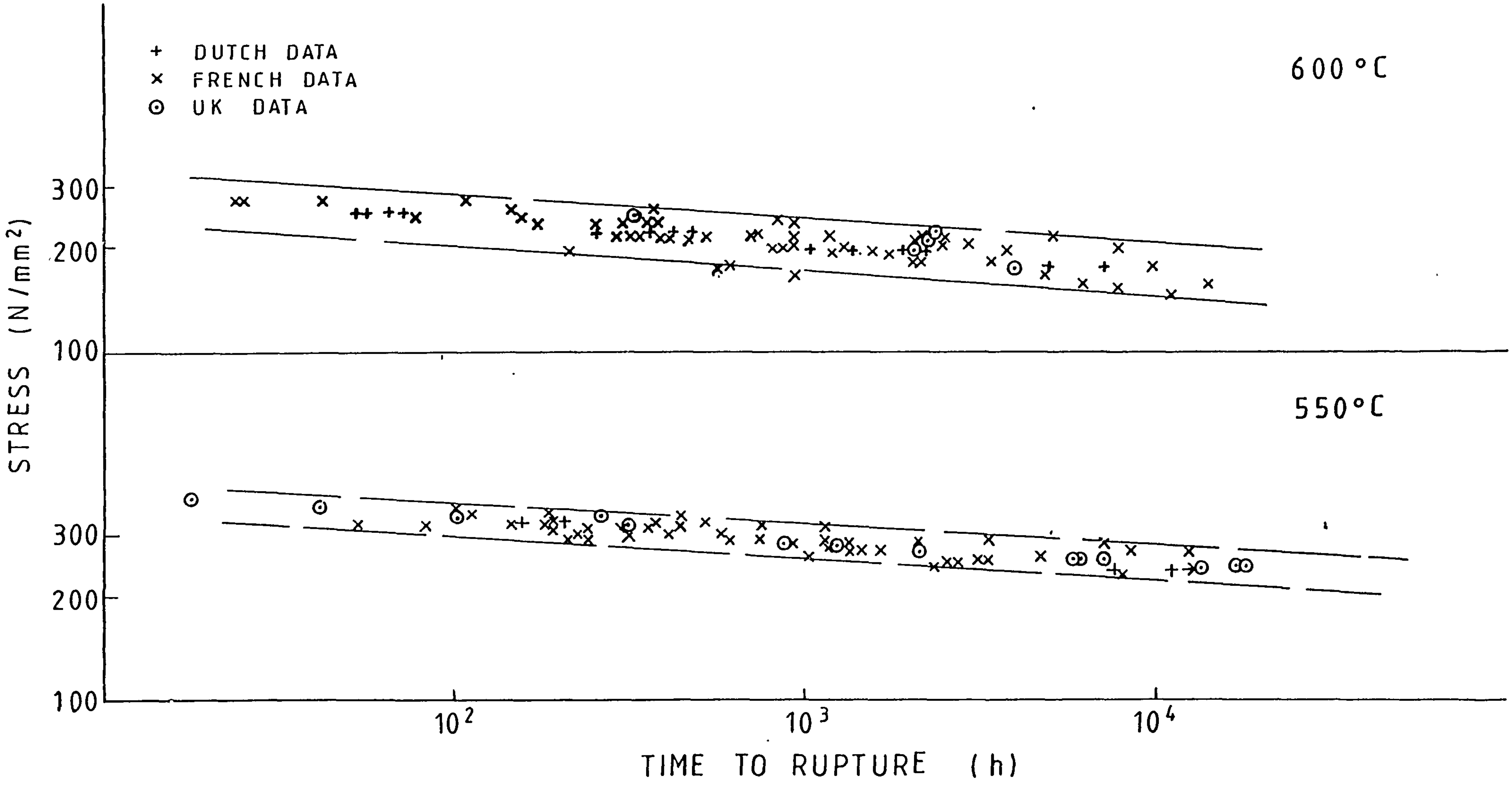

FIG. 17 STRESS RUPTURE STRENGTH OF Mo CONTAINING WELD METALS AT 550° AND 600°C

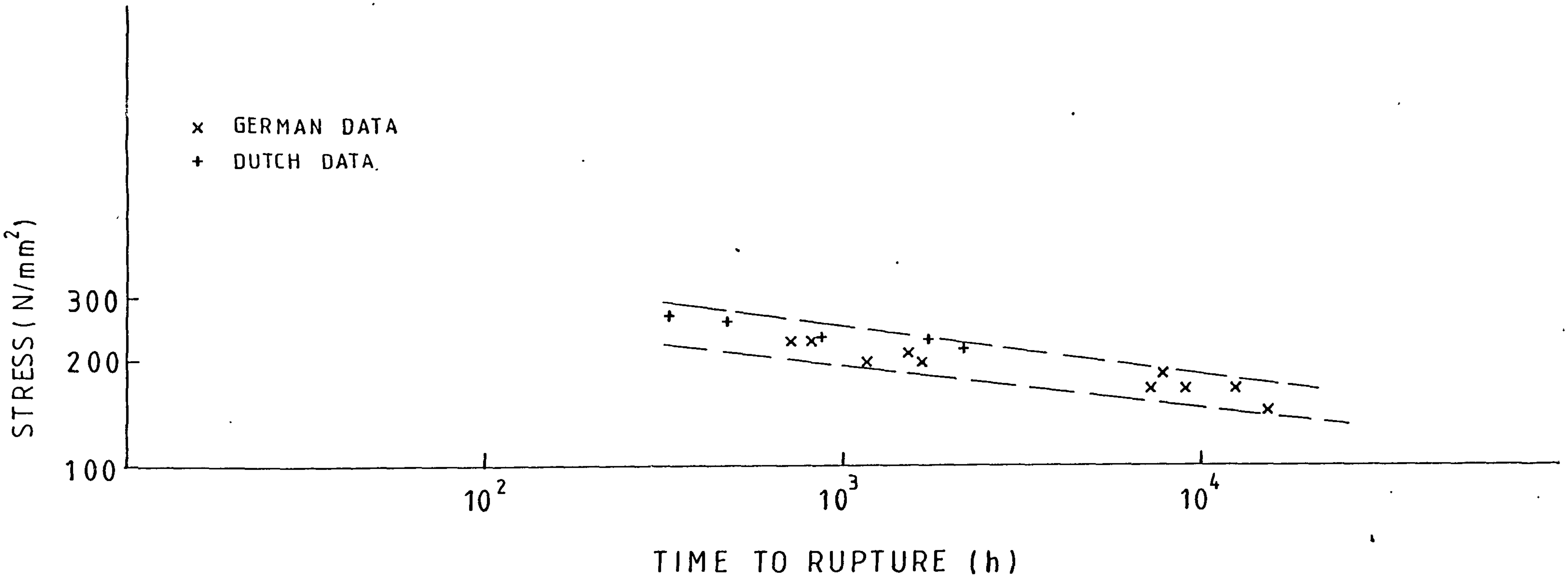

FIG.18 STRESS RUPTURE STRENGTH OF Mo FREE WELD METALS AT 550°C

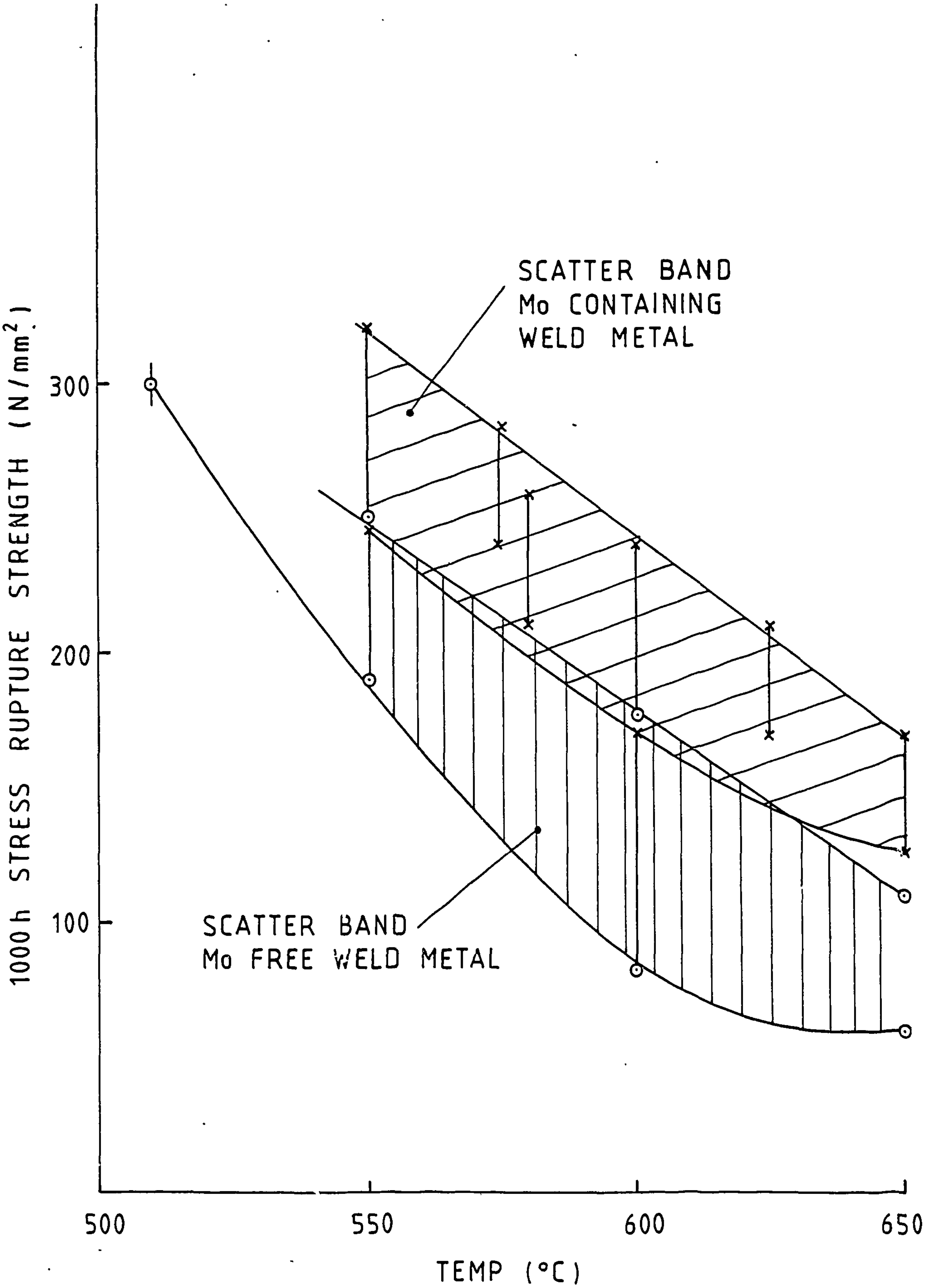

FIG. 19 1000 h STRESS RUPTURE STRENGTH SCATTER BANDS

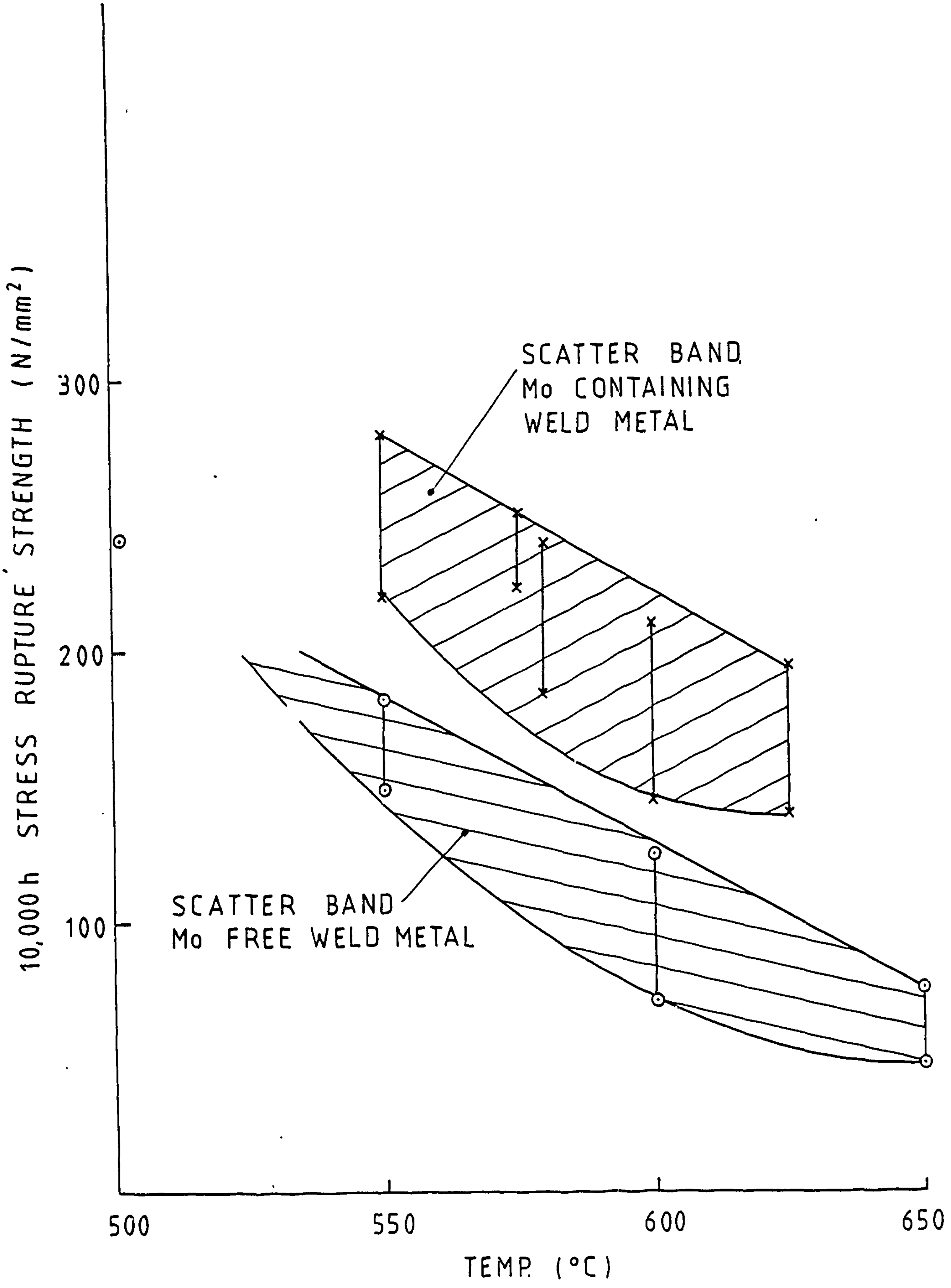

FIG. 20 10,000 h STRESS RUPTURE STRENGTH SCATTER BANDS

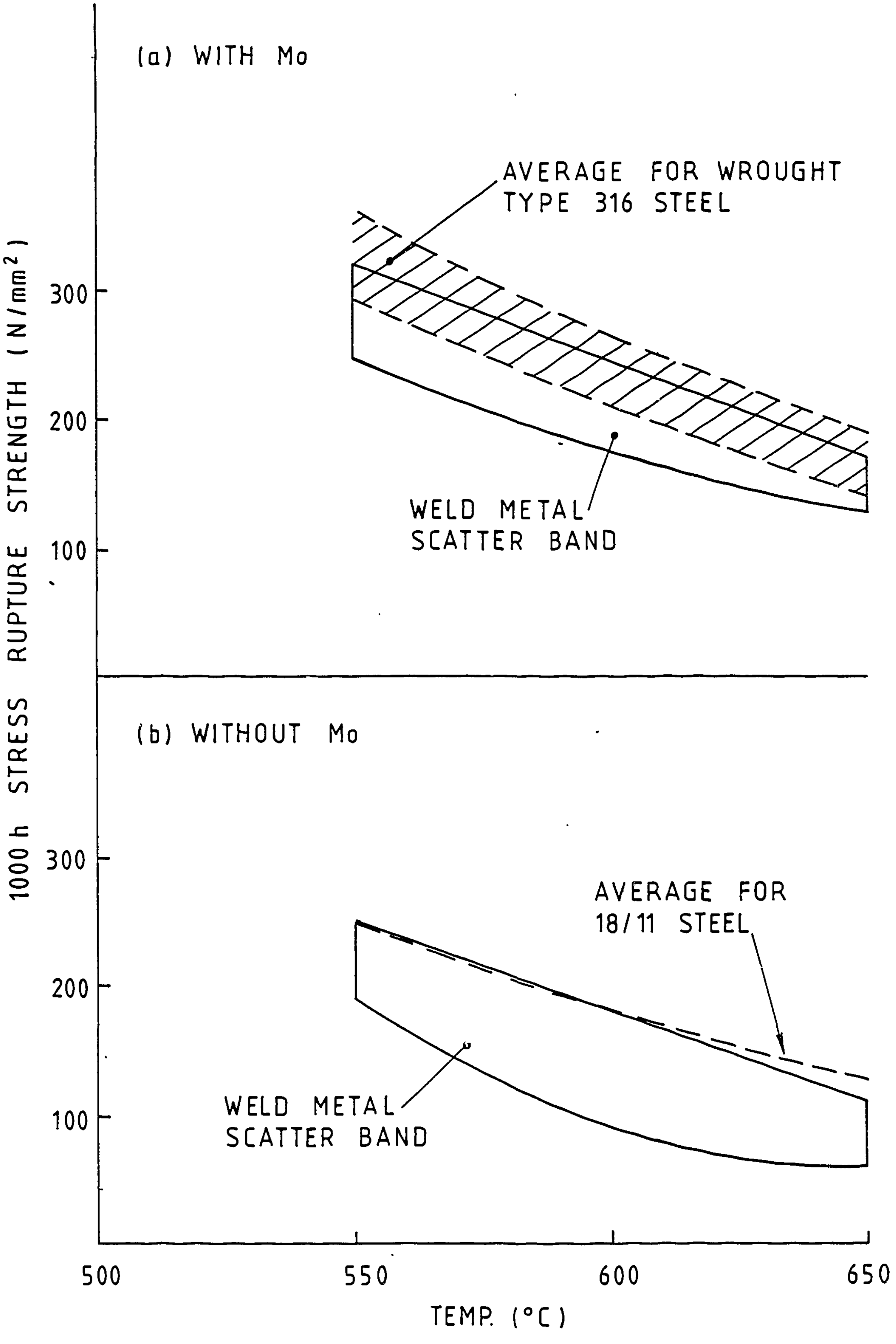

FIG. 21 1000h STRESS RUPTURE STRENGTH. COMPARISON WITH WROUGHT MATERIAL PROPERTIES

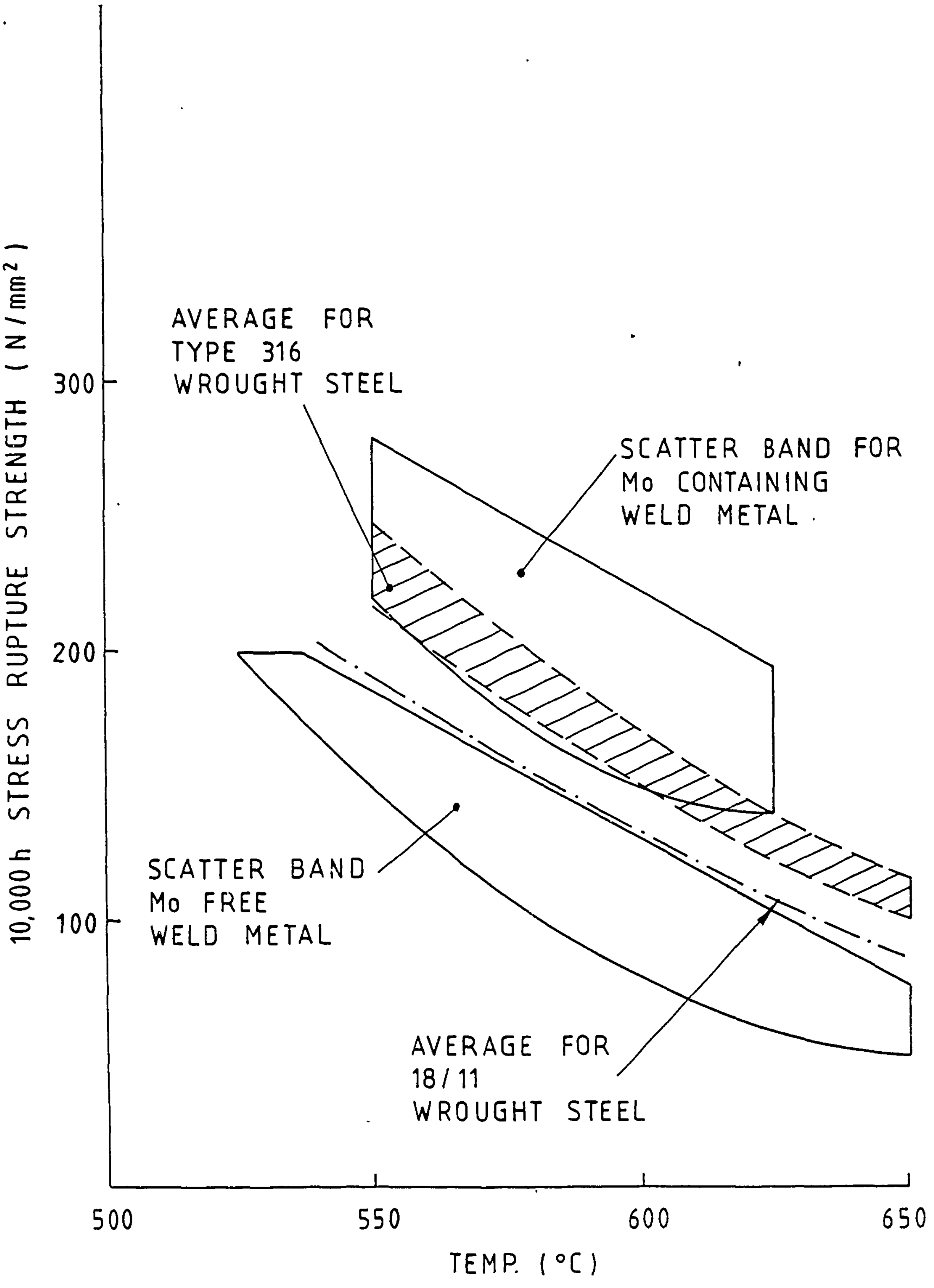

FIG. 22 10,000 h STRESS RUPTURE STRENGTH. COMPARISON WITH WROUGHT MATERIALS PROPERTIES