CRITICAL TEMPERATURE OF REINFORCING AND PRESTRESSING STEELS

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Tauno Hyvönen
Technical Research Centre of Finland
Concrete and Silicate Laboratory
Ph.Lic, Senior Research Scientist

In this paper, a change in strength properties of reinforcing and prestressing strands at the temperature range of 20 to 600 °C is discussed. The tensile tests were conducted on unwrought bars and strands at different temperatures. The strength results are given in relative strengths as a function of the temperature at testing, in which case the comparison strength is the strength obtained at a room temperature. The critical temperature as specified in the National Building Code of Finland for the steels submitted to the tests was: A 400 H: 420 °C; A 500 HW: 400 °C; A 600 H: 445 °C; B 500 P: 470 °C; Fe 37 B: 290 °C and for the prestressing strand: 380 °C.

Key words: critical temperature, reinforcing steel, prestressing strand

1. INTRODUCTION

When evaluating the fire resistance, the duration of fire, a decrease in the strength of the used reinforcing and prestressing steels when temperature increases has to be known. With an increase in temperature the structure reaches the critical temperature, in which case the strength of a material, generally the lower yield strength or the 0.2-limit, falls to the level of the existing stress and the structure looses its bearing capacity.

In the case of the concrete structure, with the critical temperature (T_{kr}) of steel it is referred to the temperature at which the yield strength of the reinforcing steel or rupture strength of the prestressing strand has dropped in the structure to the level of the steel stress corresponding to the load in the state of fire. Loading assumptions given in the National Building Code or the value which is 65 % of the yield strength of the reinforcing steel or 48 % of the tensile strength of the prestressing strand at a normal temperature are used as a steel stress.

The warming up of reinforcing steels depends on the duration of fire and the quality and thickness of the layer protecting steels. The protective layer is generally of concrete, in addition to this there can be incombustible surface and topping layers. When the thickness of the protective layer is calculated the deviation of 10 °C from the recommended value of the critical temperature of the reinforcing steel will cause as stated in the above Code the 1 mm addition to the required concrete layer or a reduction depending upon whether the critical temperature observed is lower or higher than the recommended value /1/.

Because there is no previous unified study concerning critical temperatures of the Finnish reinforcing and prestressing steels the Ministry of the Interior has included in the instructions for quality control agreements of reinforcing and prestressing steels the stipulation for the elucidation of the critical temperature.

The study has been carried out at the Concrete and Silicate Laboratory of the Technical Research Centre of Finland (VTT). The detailed results have been presented in the author's study for the degree of licentiate /2/.

2. INVESTIGATIONS

2.1 Steels used in investigations

Reinforcing and prestressing steels standardized at this time in Finland were used. The reliability of the test results were attempted to improve by sampling the steels received from almost every manufacturer as well as by examining various bar sizes, Table 1.

Table 1. Steels submitted to test; their diameters and the number of manufacturers.

Product				Number of manufacturers
Sign of product	Standard	Product	Diameter mm	
A 400 H	SFS 1210	Hot rolled deformed bar	6, 8, 10	3
A 400 HS	" 1211	Weldable hot rolled deformed bar	12, 16	3
A 400 HW	" 1213	- " -	20, 25	3
A 500 HW	" 1215	- " -	5, 6, 7, 8, 10 and 12	1
A 600 H	" 1212	Hot rolled deformed bar	6, 8 and 16	1
B 500 P	" 1256	Cold worked indented round bar		3
	" 1265	Prestressed strand; low relaxation	9.5, 12.4 12.8, 15.1	1
Fe 37 B	" 200	Ordinary structural bar	8	1

In the case of hot rolled reinforcing steels, marked with A, the desired strength (yield strength 400, 500 or 600 N/mm^2) has been achieved by a proper carbon manganese content (C: 0.15 to 0.45 %). For higher strength classes a mild alloying with vanadinum has been used. The surface of the steels belonging to the group A was ribbed (sign H).

For the cold drawn reinforcing steels, marked with B, the strength is attained by cold working low carbon mill wire, either by drawing or rolling. In this case the internal structure of the steel changes along the reduction of the cross-section and the strength increases. The amount of reduction is about 20 to 30 %. The tested cold worked steels of B 500 P, which are used mainly as steel fabric, were cold drawn. The surface of the bars were slightly indented (sign P).

The prestressing strands are products that are very heavily cold worked, in which the reduction caused by cold drawing is about 80 to 90 %. The chemical composition of this steel differs from that of reinforcing steels, e.g. C = 0.80 %. The microscopic structure of the end product, heavily cold worked perlite, differs to a great extent from the ferrite-perlite mixture of reinforcing steels. The strength properties of reinforcing and prestressing steels in the tensile tests conducted at a room temperature are shown in Fig. 1.

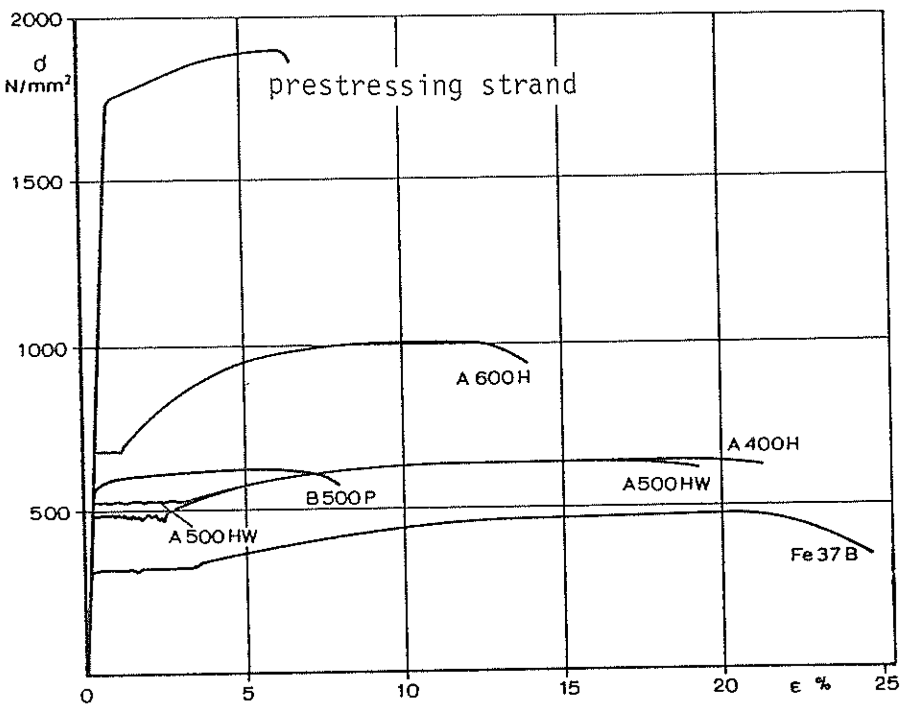

Fig. 1. Stress-strain curves of reinforcing and prestressing steels.

All other products were of Finnish make, except for A 600 H which was of Swedish origin because its domestic manufacturing is lacking at present. The prestressing strands were 7-wire low-relaxation smooth strands. Steels were made from both scraps and ore.

2.2 Testing method

The effect of temperature on the strength of steels was examined by means of tensile tests at different temperatures. The test bar was loaded in a universal testing machine and heated up by means of an electric oven around the bar (Fig. 2).

The automatic control directed heating to a desired temperature, after reaching it the bar was loaded. The real temperature of the bar was observed by three thermocouples fixed on the bar surface. The deformations of the bar were measured from the part of the bar being in the oven with a mechanical strain gauge (Fig. 2).

The reinforcing and prestressing steels used in the tests were bars still in the state of manufacture or strands, in other words, they were not worked by turning, for example.

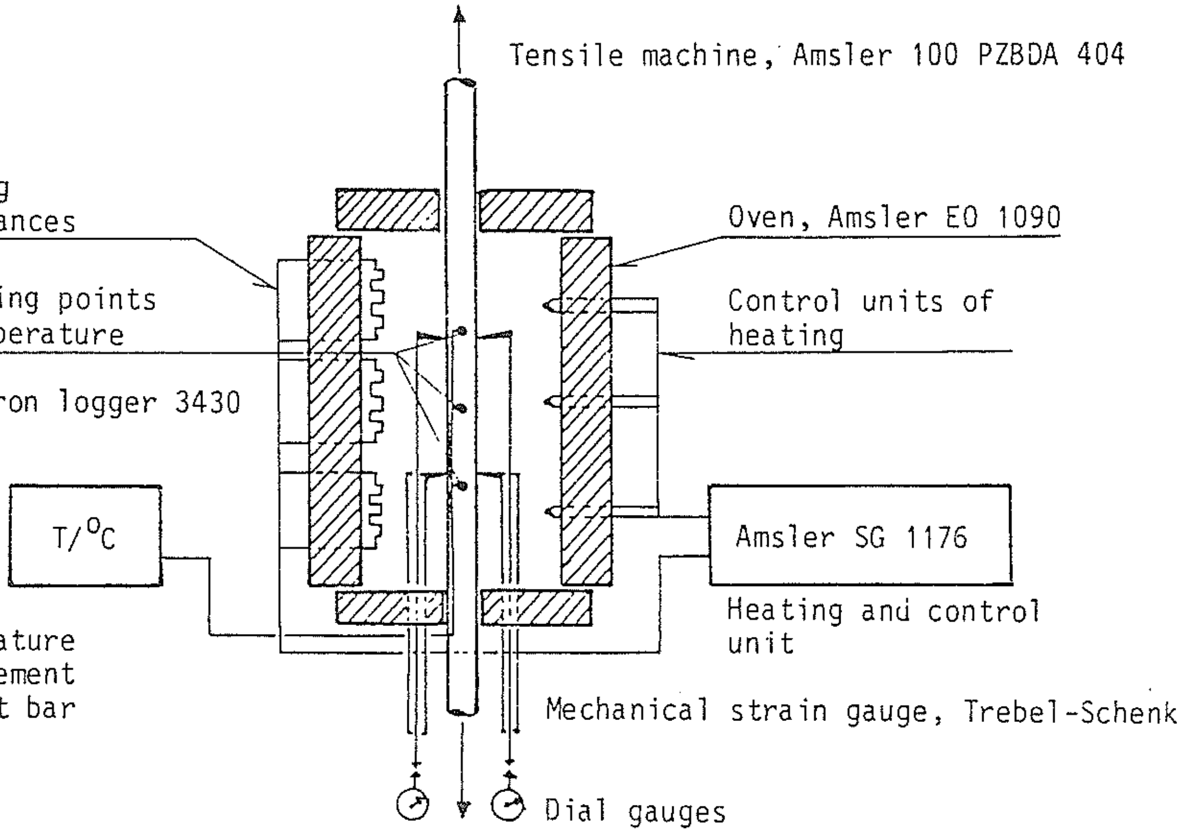

Fig. 2. Heating and measurement arrangements for the tensile test.

3. RESULTS

The results obtained, the reduction in the relative strength with an increase in temperature, are given in Figs. 3 to 9.

The relative strength expresses the ratio of the strength measured at a certain temperature to the strength measured at a room temperature,

$$\chi = \frac{R(t)}{R(20^{o}C)} \cdot 100. \qquad (1)$$

As a strength value the lower yield strength (R_{eL}) for reinforcing steels has been followed when it has appeared, in other cases the 0.2-limit has been determined. The strength unit of the prestressing strands was the tensile strength (R_m).

The curves plotted are calculated by "Stepwise-method" using the function

$$\chi = \sum_{i=1}^{i=5} a_i\, t^i. \qquad (2)$$

Temperature t is expressed in centigrades per one hundred ($^{o}C/100$). On the basis of the correlation coefficients (r) the most representative curves for each product have been selected.

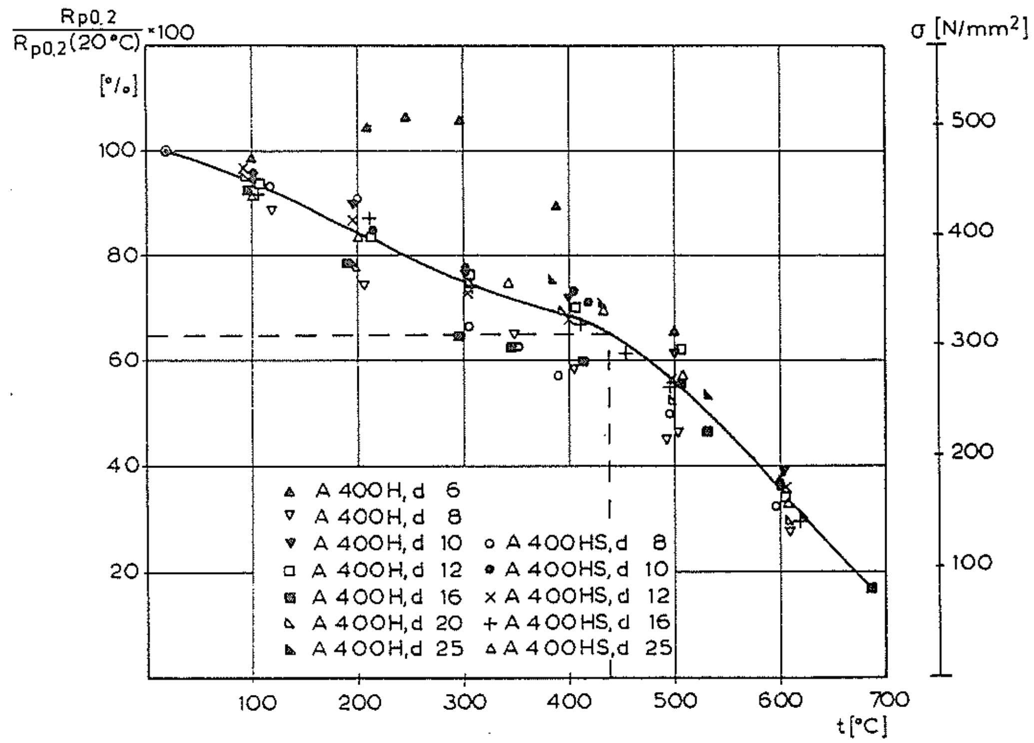

Fig. 3. Hot rolled reinforcing steels A 400 H and A 400 HS. Yield strength versus temperature

$\chi = -13.55\ t + 2.47\ t^2 - 0.35\ t^3 + 103.49 \quad (r^2 = 0.9566)$

t = temperature (^{0}C/100)

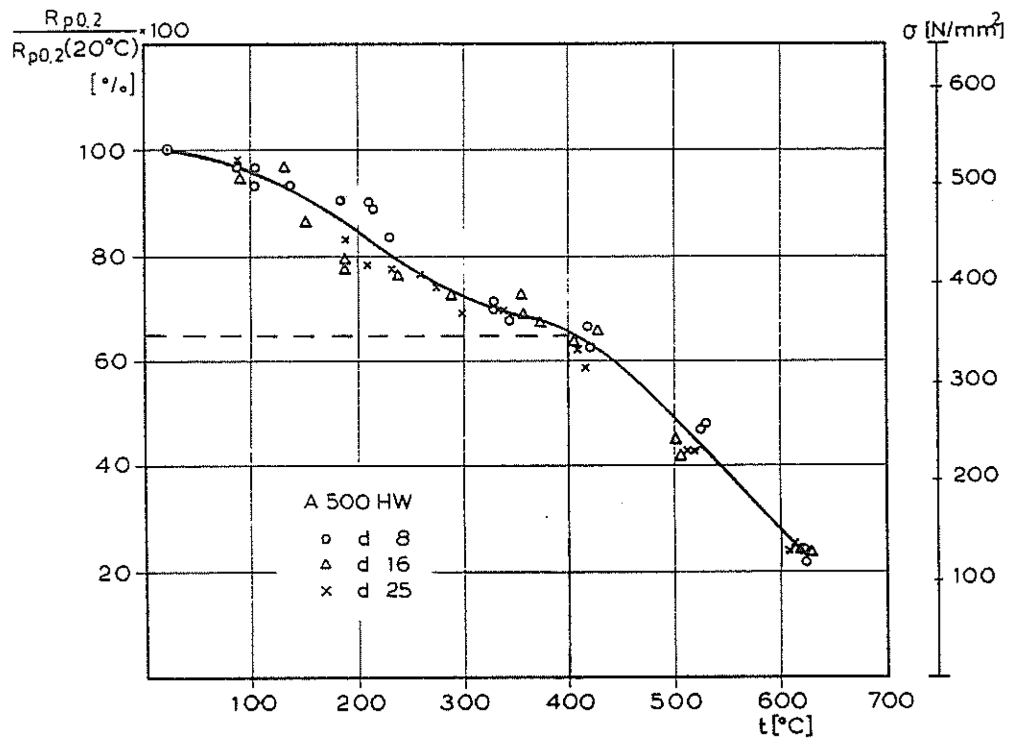

Fig. 4. Hot rolled reinforcing steel A 500 HW yield strength versus temperature

$\chi = -9.03\ t - 0.02\ t^4 + 102.36 \quad (r^2 = 0.9762)$

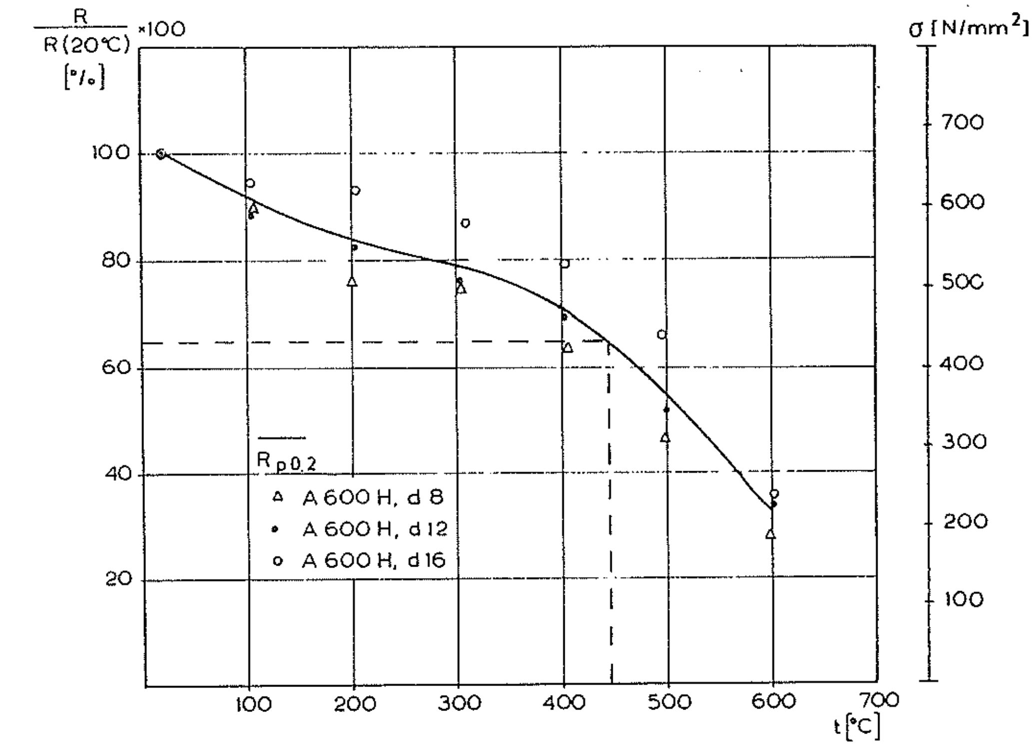

Fig. 5. Hot rolled reinforcing steel A 600 H, yield strength versus temperature

$$\chi = -14.33\ t + 3,86\ t^2 - 0,57\ t^3 + 102,52\ (r^2 = 0.9349)$$

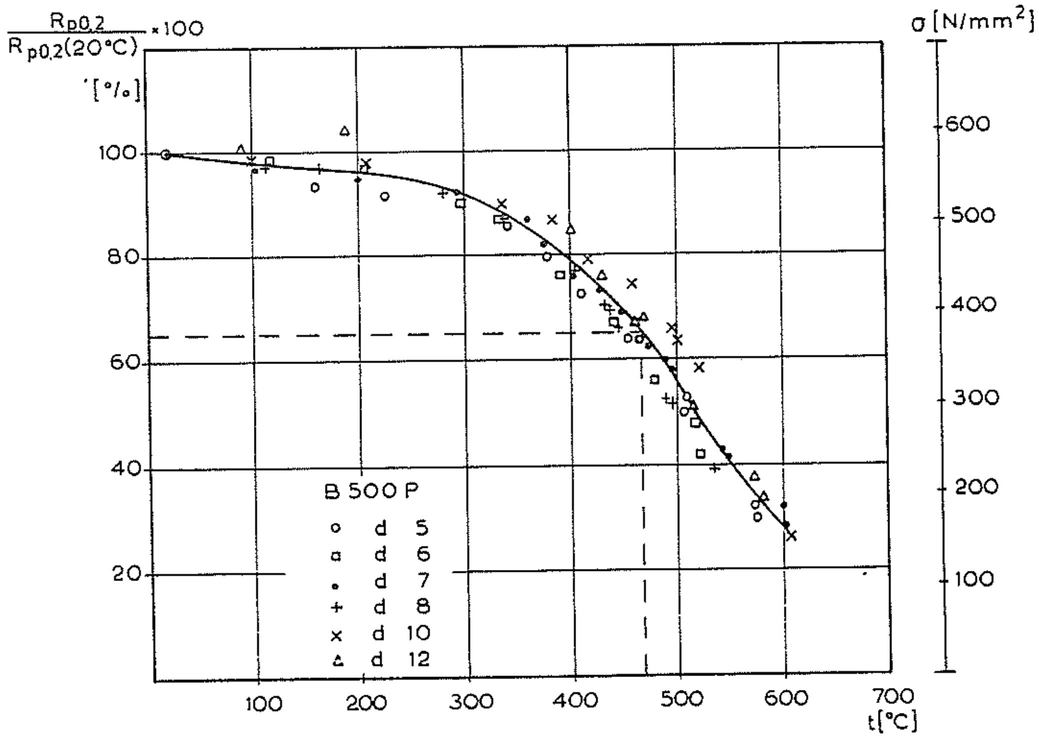

Fig. 6. Cold worked reinforcing steel B 500 P, yield strength versus temperature

$$\chi = -0.35\ t^3 + 99.68\ \ (r^2 = 0.9703)$$

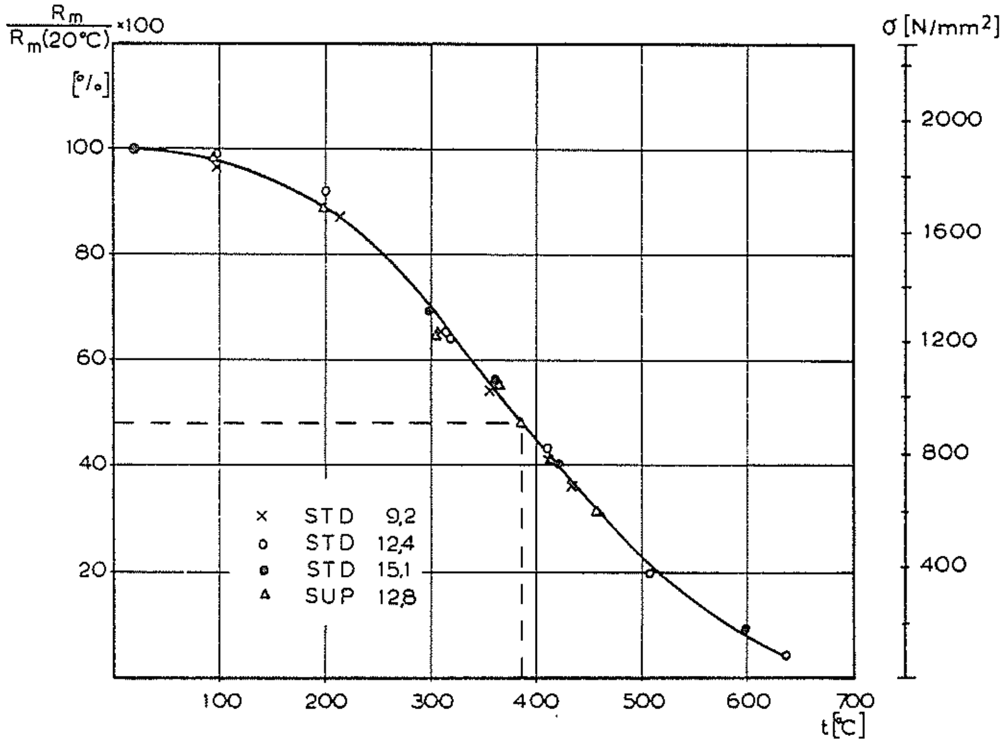

Fig. 7. Prestressing strands, tesile strength versus temperature

$$\chi = 6.22\ t - 6.12\ t^2 + 0.07\ t^4 + 98.86\ (r^2 = 0.9977)$$

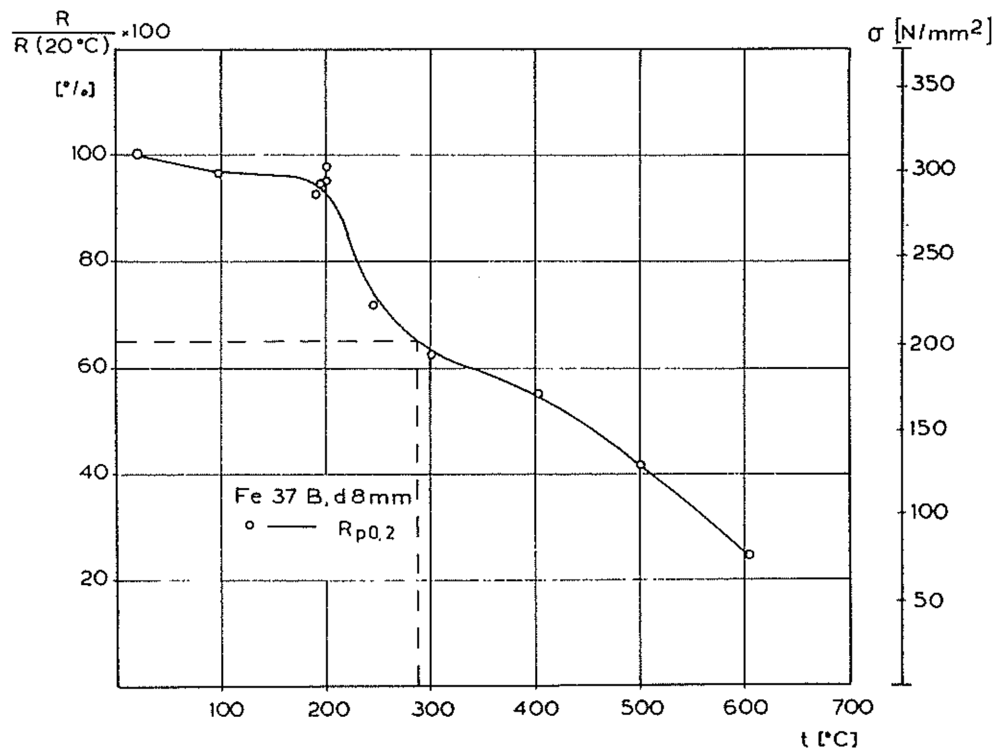

Fig. 8. Structural steel Fe 37 B, yield strength versus temperature

The regression curve was not calculated due to a small amount of observations made.

4. SUMMARY

The critical temperatures obtained for the tested steels were as follows: A 400 H(S): 420 ^oC, A 500 HW: 400 ^oC, A 600 H: 445 ^oC, B 500 P: 470 ^oC, Fe 37 B: 290 ^oC and for the prestressing strand: 380 ^oC.

When the results obtained from different products were compared with each other it was established that the results of hot rolled reinforcing steels deviated more than those of the cold worked reinforcing steels and the prestressing steels. This was to be expected on the basis of the results of quality control tests, in which the deviations of the strength results as given in annual statistics are from 7 to 8 % and the deviations of the prestressing steels below 3 %. The difference is explained by the adjustment of the manufacturing methods when passing from one product group to another.

The product Fe 37 B has been examined primarily for the sake of comparison. It is used as reinforcing steel very seldom. On account of scarce test material (one bar diameter) the regression curve (χ) has not been calculated.

The results of the products A 400 H and A 400 HS reveal the greatest deviation when all the results are treated together (Fig. 3). When the products were divided into scraps and ore based subgroups, two separate product groups with small deviation were formed. The hot strength of the scraps based bar was better (T_{cr} = 460 ^oC) than the ore-based bars (T_{cr} = 350 ^oC). The deviation is based on the difference in the chemical composition. The analysis of the tested "scraps bars" revealed elements (Cr, Ni, Mo) which raise the hot strength much more than in the case of "ore bars" analysis.

In the examination of results the ø 6 mm bar has been omitted, the results of which differ greatly from those of other dimensions. The bar in size 6 mm has been partly cold worked as a result of the manufacturing method, therefore it does not represent the typical hot rolled deformed bar A 400 H.

There was no marked difference between the weldable (A 400 HS) and unweldable (A 400 H) bars in the results.

The deviations of other hot rolled deformed bars A 500 HW and A 600 H as compared with the above mentioned one were smaller. This is influenced by the similarity of the chemical composition of steels with all bar dimensions. In both group there was products of one manufacturer only.

The results of the cold worked reinforcing bars B 500 P deviated rather slightly. Surprisingly, the hot strength of the products was higher than that of the hot rolled reinforcing steels (A 400, 500 and 600 H).

The mode of failure in all steels was ductile within the entire temperature range. When temperature exceeded 400 ^oC the strain values increased greatly. The reinforcing steels had the maximum value of local rupture strength and the minimum value of strain values in the so-called blue brittle region (150 to 300 ^oC).

SOURCE OF LITERATURE

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