BRITTLENESS AND STRENGTH OF REINFORCING STEEL BARS UNDER HIGH LOADING RATE AT LOWERED TEMPERATURES

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ABSTRACT

Cold worked and hot rolled deformed bars were loaded in rapid tensile tests at temperatures of +20, -20 and -60 °C. The possibility of brittle fracture at lowered temperatures was examined. Applied Charpy V-notch tests were also carried out.

The strengths of all steel grades in the rapid tensile tests were higher than in static tensile tests. The strain results fall below the comparison values at lower temperatures. The Charpy V-notch tests do not apparently represent the properties of reinforcing steels accurately.

Keywords: Reinforcing steels, high loading rate, low temperature, brittle fracture.

1 INTRODUCTION

In assessing the serviceability of structures, the short-term, impact-like loads must more often be taken into consideration. Loading cases such as these are produced in structures e.g. by collisions caused by heavy vehicles and aircraft crashes, by explosions attributable to accidents or a state of war, and by earthquakes. During the construction phase, e.g. in pile driving, heavy impact loads are developed.

A special feature is produced by rapid impact loads occuring at low temperatures, such as e.g. impacts arising from the handling of elements in arctic conditions.

Since the loading rate and temperature have an effect on structures and materials, the material values obtained from ordinary tests are not entirely reliable. When applying loads to reinforced concrete structures, the behaviour of tensile reinforcements must be known.

The appearance of a possible brittle fracture, e.g. during loading, was examined. Hot rolled and cold worked reinforcing steels were used in the tests.

2 GENERAL

Brittle fracture occurs suddenly without forewarning and with no preceding plastic deformation.

Brittle fracture in reinforcing steel appears as a minor strain and small reduction in the area of fracture; the fracture plane is also clearly granular. The strength values may, however, satisfy the requirements of the standard.

The ferritic crystalline structure of reinforcing steels, a body-centred cubic lattice, has itself a tendency for brittle cleavage fracture.

External factors contributing to brittle fracture are: a three-axial state of stress, a low loading temperature and a high loading rate.

Internal or metallurgical factors are: chemical composition, microstructure and state of treatment.

Three-axial states of stress in steels result from external loads, residual stresses and notches. The welds might act as notch points /2/.

Plastic deformation (yielding) occurs through dislocation movements. The dislocations start to move when the force which anchors these is exceeded through external shear force. A low temperature raises activation energy needed for this purpose. After the initial shear force has been achieved, a certain time elapses until the dislocation starts to move /1/. Under high loading rates, the stress in steel may therefore exceed the yield limit without plastic deformation.

In this manner the ultimate cleavage strength, which is not to any appreciable degree dependent on temperature, can be exceeded prior to yielding and brittle fracture occurs in a bar.

In conjunction with manufacture certain alloying elements, either added or as impurities, will penetrate the steel, thus increasing the tendency for brittle fracture. Such elements include carbon, nitrogen, phosphorus and oxygen. Their adverse effects are eliminated by the use of other alloying elements. A large grain size also has the effect of increasing the development of brittle fracture.

The treatment of steel will affect the brittle fracture tendency of an end product in such a way that, in general, cold worked steel is more susceptible to brittle fracture than hot rolled steel.

3 TESTS

3.1 Materials

In Finland, hot rolled reinforcing steel bars or alternatively cold worked reinforcing steel bars are used as reinforcement in concrete when the bar size does not exceed 12 mm.

Cold worked reinforcing steel bars in particular were examined because of their possible brittle fracture tendency. Hot rolled reinforcing steel bars were also investigated by way of comparison.

The bar types used in this investigation are shown in Table 1. In product marking the numerical value refers to the nominal yield stress requirement.

Table 1. Reinforcing steels used.

Product marking	Standard	Product	Yield stress N/mm²	Bar size mm
B525H	Tuotelehti 1)	Cold worked deformed bar	525	6, 8
B700K	Tuotelehti 1)	Cold worked deformed bar	700	6
A400H	SFS 1210	Hot rolled deformed bar	400	6, 8
A600H	SFS 1212	Hot rolled deformed bar	600	8
B525H		Fabric		6/6 6/8 8/6

1) At the time of testing both cold worked reinforcing bars were unstandardized; only one information sheet (Tuotelehti) concerning this product was available. Product B525H was later standardized according t Finnish Standard SFS 1257, and the product is marked B500K.

In order to study the welding effect, test bars with transverse bars taken from spot-welded fabric were also tested. The size of these bars and of the transverse bars is shown in Table 1.

3.2 Test arrangements

The test specimens were submitted to rapid impact-simulating tensile tests different temperatures and to impact tests emularing the Charpy V-notch tests.

In the rapid tensile tests, an axial tensile load simulating an impact load was applied to the reinforcing bars to be tested. Loading was effectuated b means of a pendulum impact hammer. The impact hammer was composed of a beam hanging from the ceiling at one end, its other end swinging freely and almo touching the floor. The test bar was fixed to an electric load cell bolted the floor in the path of the beam and parallel to the floor. When swinging, the lower end of the hammer stuck in an anvil fixed to the bar to be loaded The kinetic energy of the hammer loads the bar until failure. The loading arrangement is shown in Figs. 1 and 2.

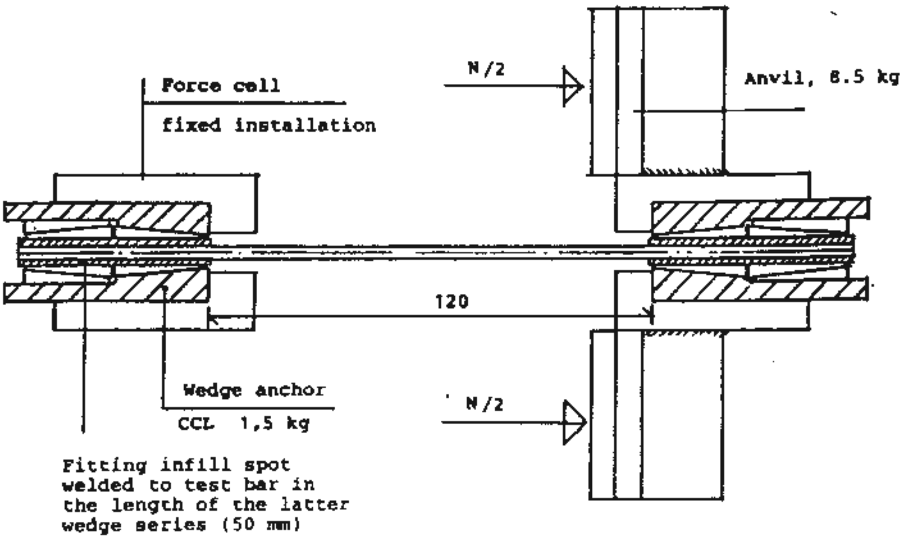

Fig. 1. Test specimen fixed to a load cell and to an anvil.

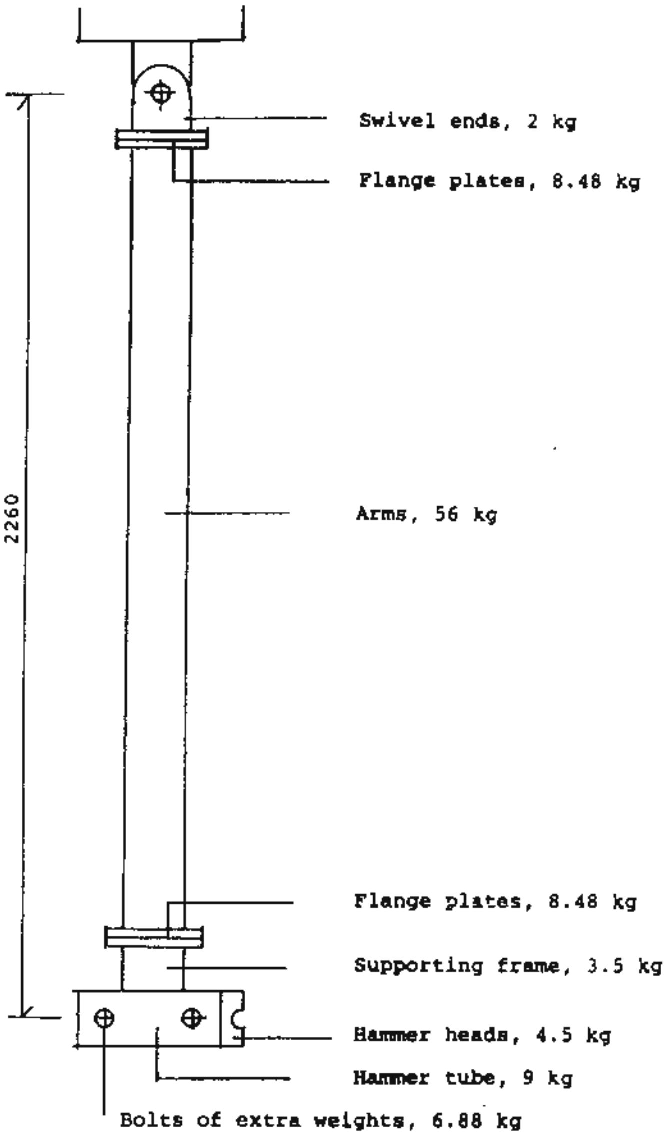

Fig. 2. Loading equipment in a rapid tensile test.

During loading the time-force curve was recorded on an oscilloscope tube. The angle of inclination of the pendulum beam after failure was also recorded and the strain in the bar was established on the basis of extension marks. The strain rate was about 10 s^{-1} under the elastic extension of the test bar. The load-extension curves were calculated from the load-time curves on the basis of background information and the measurements made.

The rapid tensile tests were carried out at temperatures of +20, -20 and -60 °C. The lowest temperatures were produced by means of carbonic acid gas. The tensile tests and calculations were carried out at Oulu University.

In the impact tests, a test specimen was used which differed from standard practice (Charpy-V-test) in that its full cross section was not square. The face of the tension side was not machined (Fig. 6) /3/.

4 RESULTS

4.1 High loading rate tensile tests

The effect of testing temperature and high loading rate on the strength properties of reinforcing steels could be clearly seen when the results of rapid tensile tests were compared with those of ordinary tensile tests. The results are presented as a system of coordinates, with the testing temperature on the x-axis and the relative result (rapid tensile test/standard tensile test) on the y-axis. The diagram shows the tensile strength (R_m), the 0.2-proof stress ($R_{p0.2}$) and the strain at failure (A_{130}). The unusual measure (130 mm) of the strain at failure results from test arrangements.

The mean strength results of the tests on cold worked reinforcing steel bars B525H and B700K are given in Figs. 3 and 4 and those of the tests on hot rolled reinforcing steel bars A400H and A600H are given in Fig. 6.

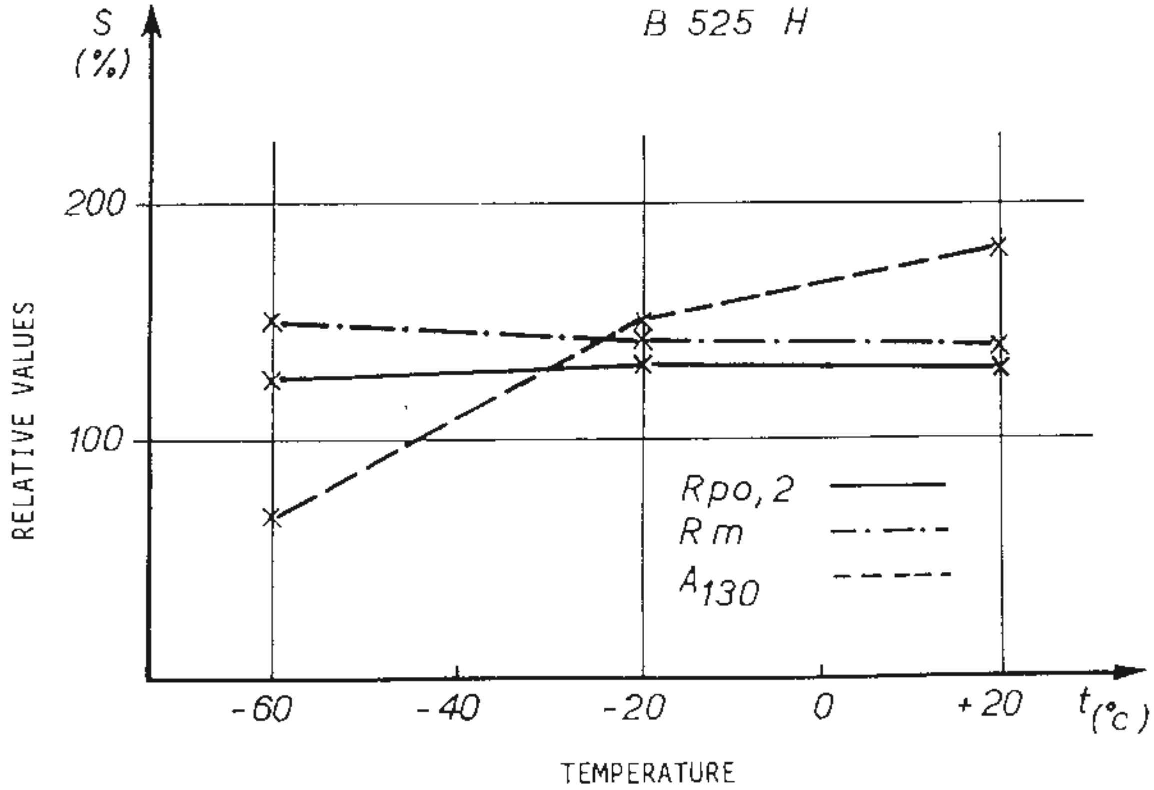

Fig. 3. Mean strength results of cold worked deformed bar B525H including both welded and unwelded test bars.

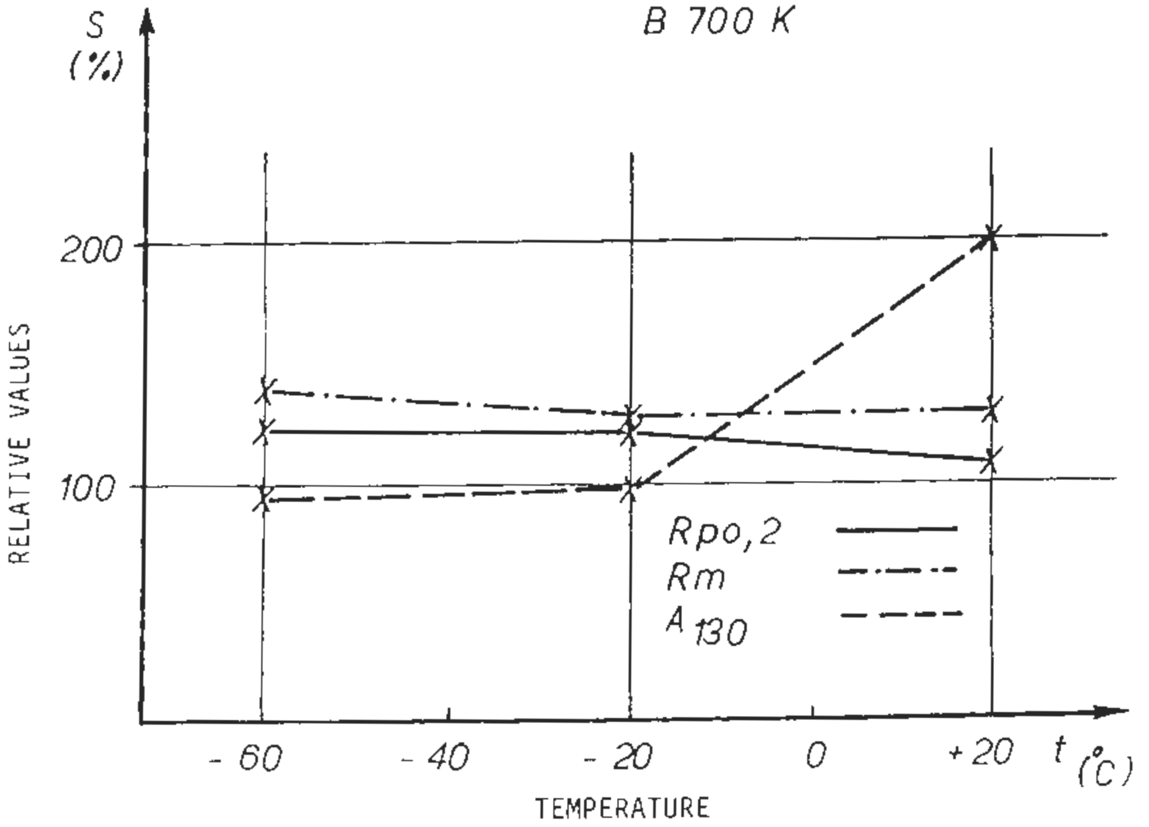

Fig. 4. Mean strength results of cold worked deformed bar B700K.

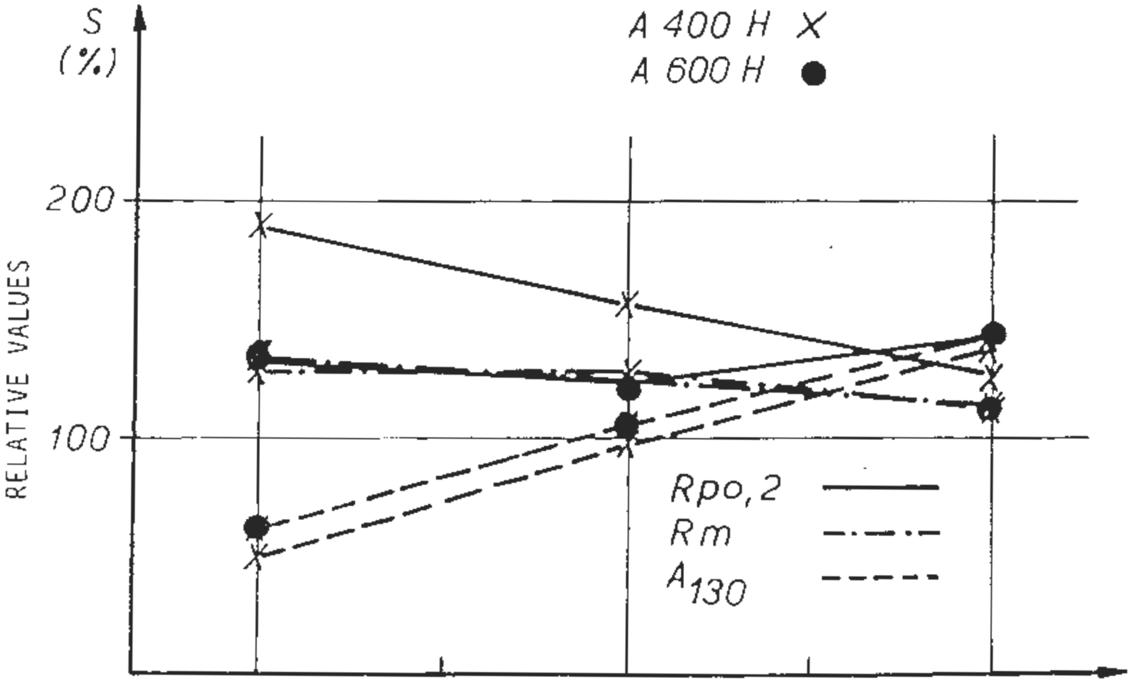

Fig. 5. Mean strength results of hot rolled deformed bars A400H and A600H.

In the results of product B525H no distinct difference could be found when using welded or unwelded bars. Therefore the results are marked as mean strength results on the same diagram.

4.2 Applied Charpy V-notch tests

The results of the applied Charpy V-notch test are given in Fig. 7.

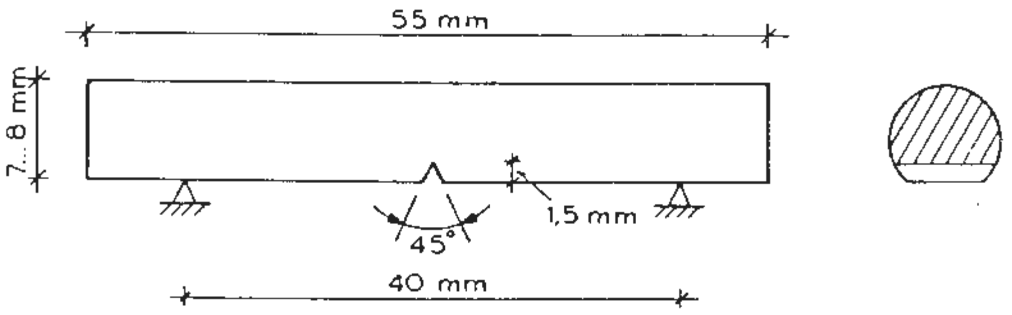

Fig. 6. Test specimen used in impact tests.

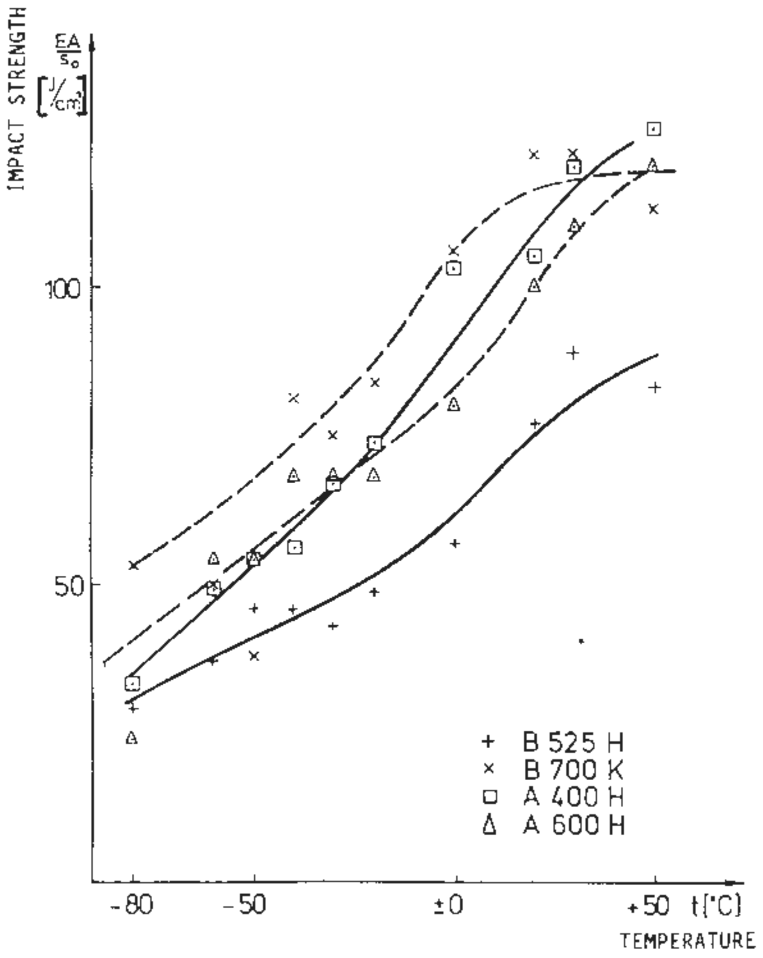

Fig. 7. Results of applied Charpy V-notch test.

In the impact tests the number of test specimens was small, thus the results are only of an indicative nature. The usual method of examination of notch toughness indicated that the transition temperature was about -20 °C.

5 SUMMARY

According to the results obtained from the rapid tensile tests the strength values of all steel grades were almost 1.5 times as much as the comparison strengths.

The strain values at temperatures of +20 to -20 °C were greater than the comparison values; at lower temperatures the strain values decrease below the comparison level.

Any real brittle fracture could hardly be noticed, only in the case of product B700K a slight brittle fracture tendency at the lowest temperatures was observed from SEM fractographs.

The rapid tensile tests indicated that the reinforcing steel bars possessed better ductility properties than could have been concluded from the results of the applied Charpy V-notch tests. It seems that the behaviour of reinforcing steel bars under loading conditions is not accurately shown by the Charpy V-notch tests.

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