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Investigations of the frequency influence on the fatigue behavior of reinforcing steel

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1 Introduction

High-rise buildings, wind turbines, bridges, etc., suffer a high number of dynamic loads throughout their service life. The problem with this dynamic load is that it causes damage to the material's structure even if the stress is below the static strength of that material. After a while, this damage can lead to a fatigue failure of the material, causing a drastic reduction in the reliability of reinforced concrete structures respectively of these buildings. The fatigue behavior of reinforcing steel can be investigated in a uniaxial fatigue test according to DIN EN ISO 15630-1 [1]. This study aimed to investigate the problem of heat development in specimens throughout a limitation of the test frequency f.

2 Theoretical background

Material fatigue is the damage or failure of material and components caused by time-varying, frequently repeated strain.

Cracks are formed preferably at defects, notches, and cross-sectional transitions. The cracks increase with further load cycles, and finally, the residual fracture occurs. This fatigue fracture transpires at a stress level far below the static strength level of the material. In addition, fatigue cracks often initiate brittle fractures, and fatigue can also play a part in corrosion and wear. [2] [3]

The influencing factors on the fatigue behavior can be classified into three categories: surface, manufacturing and testing.

Since the testing conditions are one of the influencing factors on the fatigue behavior of reinforcing steel, test standards such as DIN EN ISO 15630-1 [1] regulations were applied to the tests performed in order to keep these influences as low as possible. The test standards for the uniaxial fatigue test of reinforcing steel provide specifications of the specimens, test equipment, and test method. By limiting the test frequency between 1 and 200 Hz, it is aimed to limit also the temperature below 40°C.

3 Methodology

The uniaxial fatigue tests were carried out on reinforcing steel from the same manufacturer type: B500B hot-rolled and cold-stretched, consisting of four transverse ribs with 12 mm, 16 mm, and 20 mm diameters.

After the specimen preparation (cutting to the appropriate length, sandblasting both ends to minimize a failure in the clamping area) they were tested in a high frequency pulsator 15 HPF 422 from Alfred J. Amsler & Co. (retrofitted). Before testing five temperature sensors were applied to the surface of the reinforcing steel, two more were applied on the outside of the clamping area (Figure 1). Three further temperature sensors were placed in the test chamber to control the surrounding area.

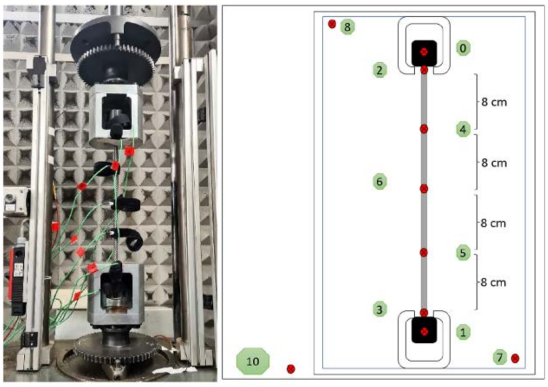

Figure 1: The positions of the ten temperature sensors attached to the specimen.

The four test parameters investigated in this study were chosen to be the specimen length, diameter, stress range, and frequency.

The variations in the diameter and length of the specimen lead to alterations in the mass undergoing oscillations, which, in return, affect the energy input, inducing changes in internal friction and temperature.

Stress range and frequency were recognized as related parameters, where an increase in the amplitude of the applied force directly corresponds to the acceleration and displacement of the specimen, thereby influencing the oscillation frequency.

Three termination criteria were a priori given: Runouts after reaching 2 million load cycles, fractures in the clamping area or a failure of the specimen in the free length.

4 Experimental results

Figure 2 introduces the S-N curve of the results obtained from the uniaxial fatigue test carried out according to DIN EN ISO 15630-1 [1]; on the x-axis the number of load cycles N in a logarithmic scale, and on the y-axis the stress range $\Delta\sigma$ also in a logarithmic scale are illustrated.

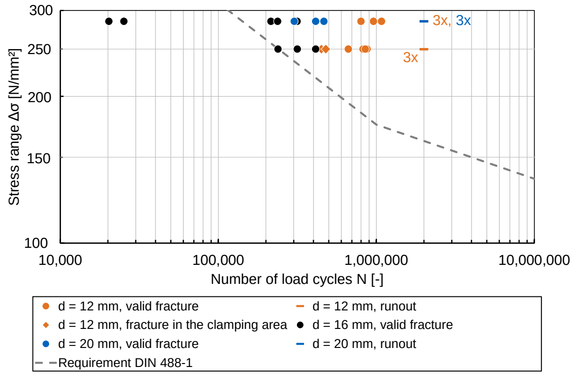

Figure 2: S-N curve of the obtained fatigue results.

Figure 3 shows the temperature development during the uniaxial fatigue test (d = 12 mm, $\Delta\sigma$ = 285 N/mm², f = 128 Hz). It can be seen that all sensors (no. 7, 8 and 10) in the test chamber were subjected to constant laboratory conditions throughout. The sensors, which were applied externally to the clamping (no. 0 and 1), detect a temperature increase during the test. All sensors on the specimen surface show a stronger temperature increase. The origin of failure was located between sensors no. 3 and 5. A sharp increase in temperature can be seen at the time of failure. At this time the temperature exceeds the 40°C.

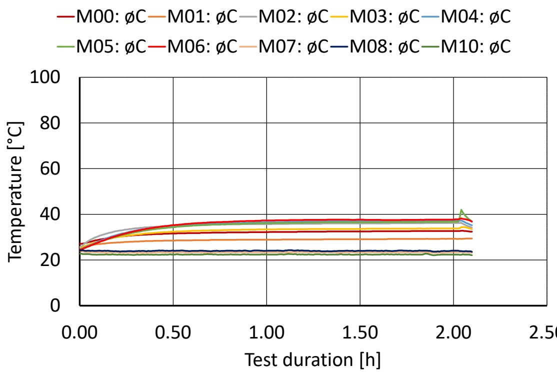

Figure 3: Temperature development of one specimen from test series number 2 (d = 12 mm, $\Delta\sigma$ = 285 N/mm², f = 128 Hz).

The same effects can be seen in Figure 4 (d = 16 mm, $\Delta\sigma$ = 285 N/mm², f = 154 Hz). However, a temperature increase above 40°C can be observed for all sensors placed on the surface and also externally on the clamping.

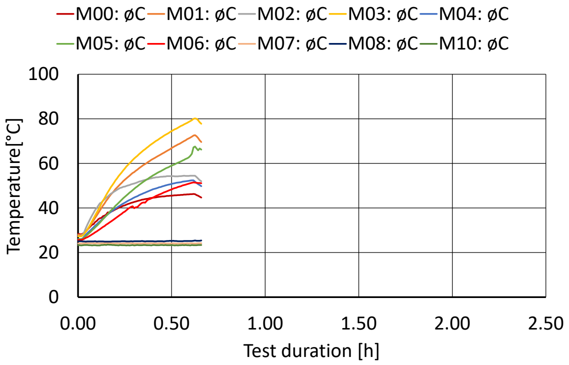

Figure 4: Temperature development of one specimen from test series number 4 (d = 16 mm, $\Delta\sigma$ = 285 N/mm², f = 154 Hz).

5 Conclusion and outlook

In this study different influencing factors on the heat development in uniaxial fatigue tests were observed.

Identical lengths and stress ranges but different diameters and frequencies show various heat developments. A higher heat development was observed with increasing frequency and mass.

The temperature in the specimens can reach values above 40°C which was not intended in this investigation since the frequency was limited to 200 Hz. For further studies it can be suggested to adjust the test parameters in order to keep the specimen's temperature below 40°C. Therefore, other dimensions and frequencies could be investigated.

6 Literature

[1] DIN EN ISO 15630-1:2019, Stähle für die Bewehrung und das Vorspannen von Beton-Prüfverfahren, Teil 1: Bewehrungsstäbe, Walz-draht und Draht, Deutsches Institut für Normung e.V., Berlin, 2019.

[2] Gehlen, C.; Kränkel, T.; Meng, B.; Osterminski, K.; Meyer, F.; Schröder, P.: Baustoffe im Betonbau in Handbuch für Bauingenieure, Zilch, K. et al. (eds). Wiesbaden: Springer Vieweg, 2020, pp. 1-63.

[3] V. Läpple: Einführung in die Festigkeitslehre, Lehr- und Übungsbuch, 1. Auflage, GWV Fachverlag, Vieweg Wiesbaden, 2006.