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# Mechanical material properties for the decay phase of real fire scenarios (CoolFire) | AiF No.: 20915N

## Summary of the research project AiF No.: 20915N

Fire resistance design is an important aspect for the safe and cost-efficient design of steel structures in building and industrial construction. In the event of fire, the load-bearing capacity of a structure depends on its ability to withstand mechanical and thermal loads despite the reduction in material strength and stiffness. In practice, in addition to simplified calculation methods, more and more advanced calculation methods are being used for design. Advanced design methods taking real fire scenarios into account have the potential to increase planning reliability and reduce the costs and expenditure for fire safety measures. An important basis for the calculation are suitable constitutive material models, which realistically represent the behavior of steels during the entire fire. This includes the cooling phase of real fire scenarios and the material behavior after a fire event.

To describe the temperature-dependent material behavior of structural steel for fire resistance design, EN 1993 1 2 provides a stress-strain model that accounts for reduction factor-temperature relationships. For normal-strength structural steel, this may be used within the framework of advanced calculation methods taking into account natural fire curves for both the heating-up or full-scale fire phase and the cooling phase. In the course of the further development of Eurocode 3 to the next generation, prEN 1993 1 2 will see an extension of the application limits of the mechanical material model to structural steel up to and including S700. However, due to a lack of research results regarding the cooling behavior of high-strength structural steels, this extension is initially limited to the heating and full-fire phase for steel grades above S500. The goal here is to accurately describe the material behavior of the latter structural steels, including during the cooling phase of natu-ral fires. Against this background, the material behavior of normal, high and ultra-high strength structural steel in the event of fire was systematically investigated, with particular attention being paid to the cooling phase of natural fires.

Extensive natural fire tests were carried out on normal-strength structural steel S355 J2+N as well as high-strength, tempered structural steel S690QL and ultra-high-strength structural steel S960QL. In addition, a database was created for the stress-strain behavior of struc-

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tural steel under temperature loading and evaluated from results of tensile tests on normal-strength and high-strength structural steels at elevated temperatures from the literature. Based on the data and test results, the constitutive material model for structural steel in fire conditions according to prEN 1993 1 2 was critically evaluated and further developed.

The test results have shown that normal strength structural steel S355 exhibits an almost completely reversible behavior after a fire, provided that the temperature during the fire process does not exceed the A1-temperature, meaning that the constitutive material model according to prEN 1993 1 2 essentially describes the temperature-dependent behavior of nor-mal strength structural steel accurately for all fire phases. The model has also proven suitable for application on high-strength, tempered structural steel during the heat-ing and full-burn phase of a fire. However, it was found that the cooling behavior of high-strength structural steels is different from that of normal-strength structural steel. Although the stiffness of the materi-al is also completely reversible after expo-sure to temperature, the recovery of strength depends largely on the maximum temperature during the heating phase. Higher temperatures mean that the initial strength cannot be regained after com-plete cooling. This could also be observed at temperatures below the A1 temperature. Based on the test results, a model proposal was developed for ap-plication to high-strength structural steel during the cooling phase of real fire sce-narios (see Figure 1). For this purpose, the existing material model according to prEN 1993 1 2 is extended by an additional re-duction factor-temperature relationship depending on the maximum temperature reached in the heating/full firing phase for the strength development during cooling. By integrating the additional reduction factor-temperature relationship using tabular values or optionally simple linear equations into the already known materi-al model for structural steel in fire condi-tions, easy handling for engineering prac-tice is enabled. Planning offices and steel construction companies, which are pre-dominantly SMEs, now have a simple tool for fire resistance design based on well-known procedures at their disposal, which can be used immediately and without additional effort.

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