# ISOTHERMAL MATERIAL TESTS OF COLD WORKED STAINLESS STEELS

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Abstract

*The stress-strain relationship of the material at elevated temperatures is required for determining the load-bearing capacity of structure under fire conditions. This article describes the testing programme and results for isothermal material tests at elevated temperatures for cold worked stainless steels. The main objective of the tests is to provide data for fire design guidance. Stress-strain relationships at elevated temperatures were determined with steady-state tensile tests for three cold worked austenitic stainless steel EN 1.4318 (Polarit 711), EN 1.4571 (Polarit 761) and EN 1.4541 (Polarit 731). The tests were performed by AvestaPolarit Stainless Oy.*

*The strength values at elevated temperatures are defined through the reduction factors. On the basis of steady-state tests the stress values in relation to proof strains of 0.1%, 0.2%, 1.0%, to total strain 2.0% and to the tensile strength were determined as well values of modulus of elasticity for cold worked materials. These values were compared with values presented in prEN 1993-1-2 [1].*

## 1 INTRODUCTION

The fire resistance time depends on the strength of the material, on the dimensions and shape of the cross-section and, naturally, on the reduction factor for the design load level for the given fire situation. The stress-strain relationship of the material at elevated temperatures is required for determining the load-bearing capacity of structure under fire conditions. Where mechanical resistance in the case of fire is required, the structure should be designed and constructed in such a way that it maintains its load bearing function during the relevant fire exposure. Also deformation criteria should be applied where the means of fire protection, or the design criteria for separating elements, require the deformation of the load bearing structure to be considered [2].

Stress-strain relationships at elevated temperatures were determined with steady-state tensile tests for three austenitic stainless steel EN 1.4318 (Polarit 711), EN 1.4571 (Polarit 761) and EN 1.4541 (Polarit 731) (Table 1). The tests were performed by AvestaPolarit Stainless Oy. The material properties were determined for cold worked materials.

This article describes the testing programme and results of isothermal material tests (steady-state tests) at elevated temperatures for cold worked material. The main objective of the tests is to provide data for fire design guidance. The strength values at elevated temperatures are defined trough the reduction factors. On the basis of steady-state tests the stress values in relation to proof strains of 0.1%, 0.2%, 1.0%, to total strain 2.0% and to the tensile strength were determined as well values of modulus of elasticity.

According to prEN 1993-1-2 [1] the strength at 2% total strain is used in determining the structural fire resistance of stainless steel members of Classes 1, 2 and 3. The reduction factor corresponding the strength at 2% total strain is determined with parameter $g_{2,\theta}$ and the relation between $f_{0,2}$ and $f_u$ is also taken into account. However, in situations which require consideration of the deformation criteria, the strength at a total strain of 1,0%, $f_{1,\theta}$ is recommended as a basis for the calculations instead of $f_{2,\theta}$. According to prEN 1993-1-2 [1] 0.2% proof strength values are used in determining the structural fire resistance of Class 4 stainless steel members.

# 2 TESTING PROGRAMME

In steady-state tests the temperature is kept constant and the load is changed. In steady-state tests the load rate in the test has an effect on the test results. The stress at a given strain tends to decrease with decreasing rate. The straining rate was 0.5 %/min from the beginning of the test to the yield stress. After 0.2% proof strain the straining rate was increased up to 20%/min. The straining rates in tests were acceptable according to SFS-EN 10002-5 (1992) [3]. Stainless steels may behave quite differently under tension and compression. Here the stress-strain curves at elevated temperatures have been determined only by tensile tests.

**Table 1** Mechanical properties of cold worked materials of EN 1.4318 EN, 1.4571 and EN 1.4541 at room temperature.

| | **0.2%-proof stress** $R_{p0.2}$ **[N/mm²]** | **1.0%-proof stress** $R_{p1.0}$ **[N/mm²]** | **Tensile strength** $R_m$ **[N/mm²]** | **The modulus of elasticity [kN/mm²]** | **Elongation after fracture A50 %** |
|---|---|---|---|---|---|
| EN 1.4318 (Polarit 711) (annealed according to EN 10088-2) | 569<br>(350) | 611<br>(380) | 919<br>(650 to 850) | 187<br>- | 33<br>(40) |
| EN 1.4571 (Polarit 761) (annealed according to EN 10088-2) | 731<br>(240) | 846<br>(270) | 880<br>(540 to 690) | 172<br>- | 17<br>(40) |
| EN 1.4541 (Polarit 731) (annealed according to EN 10088-2) | 629<br>(220) | 736<br>(250) | 837<br>(520 to 720) | 178<br>- | 26<br>(40) |

Steady state tests were performed at temperature intervals of 100°C up to the temperature 500°C and after that the interval was 50°C. The steady-state tensile tests were carried out up to 1100°C. Two equal tests were performed at each temperature and if where there was a significant disparity in the results, a third test was performed. Tensile tests at room temperature were also carried out.

# 3 TEST RESULTS

In contrast to carbon steels the stress-strain relationship of an austenitic material is strongly non-linear also at room temperature. Because the material has no precise yield point, the yield stress is usually defined by reference to 0.2% proof strain.

The strength values at elevated temperatures are here presented by the reduction factors. Figure 1 compares the reduction factor of 0.2% proof strength of materials EN 1.4318 and EN 1.4571 with the reduction factors according to prEN 1993-1-2 [3]. Values of 0.2% proof strength are used for fire design of Class 4 stainless steel sections.

Figures 2 and 3 shows the reduction factor of the stress relation to measured total strain of 2%. In determining the structural fire resistance of stainless steel members of Classes 1, 2 and 3 the strength at 2% total strain is used. The corresponding reduction factor is determined with parameter $g_{2,\theta}$ and the relation between $f_{0,2}$ and $f_u$ is also taken into account.

$$f_{2,\theta} = f_{0,2\text{proof},\theta} + g_{2,\theta}(f_{u,\theta} - f_{0,2\text{proof},\theta}) \qquad (1)$$

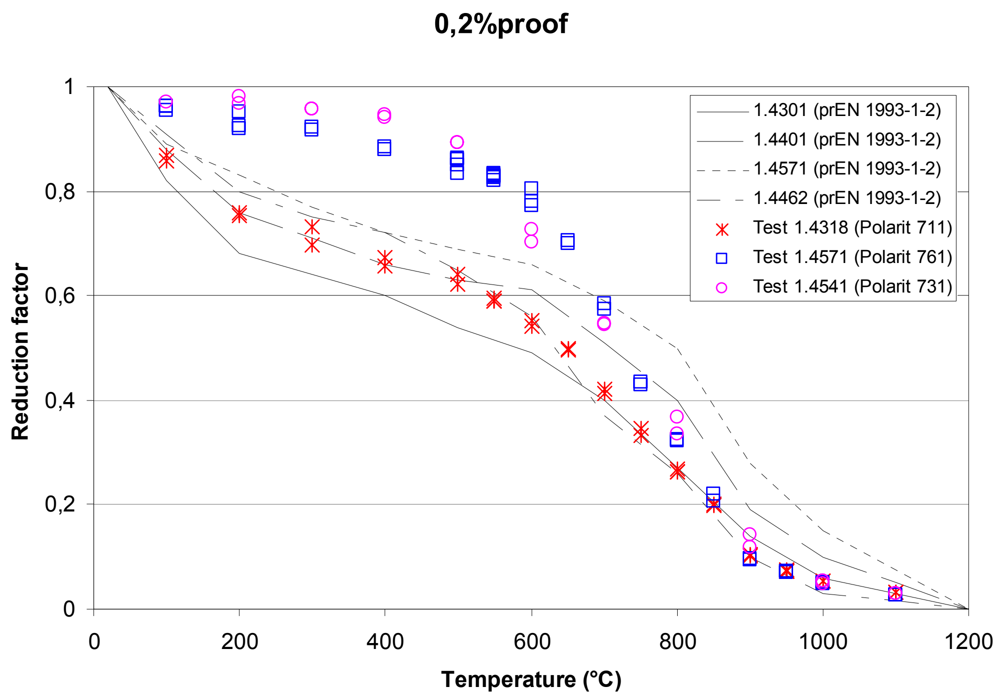


**Figure 1.** Reduction factor of 0.2% proof strength of EN 1.4318 (Polarit 711), EN 1.4571 (Polarit 761) and EN 1.4541 (Polarit 731) determined by isothermal tests and compared with the values of prEN 1993-1-2 [1].

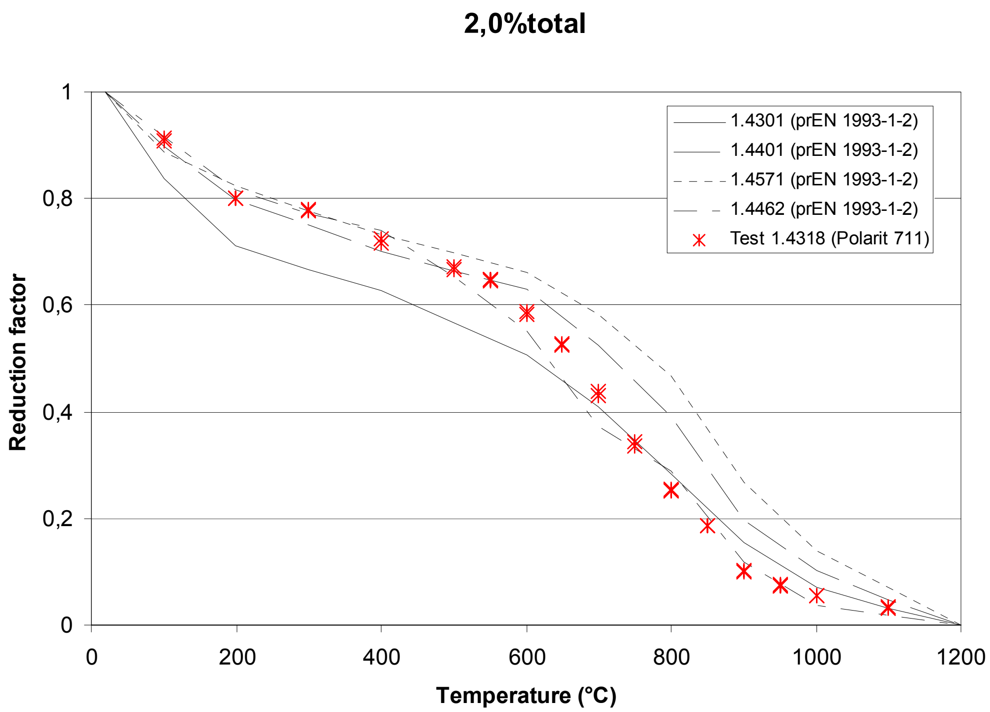


**Figure 2.** Reduction factor of strength at 2.0% total strain of EN 1.4318 (Polarit 711) determined by isothermal tests and compared with values according to prEN 1993-1-2 [1].

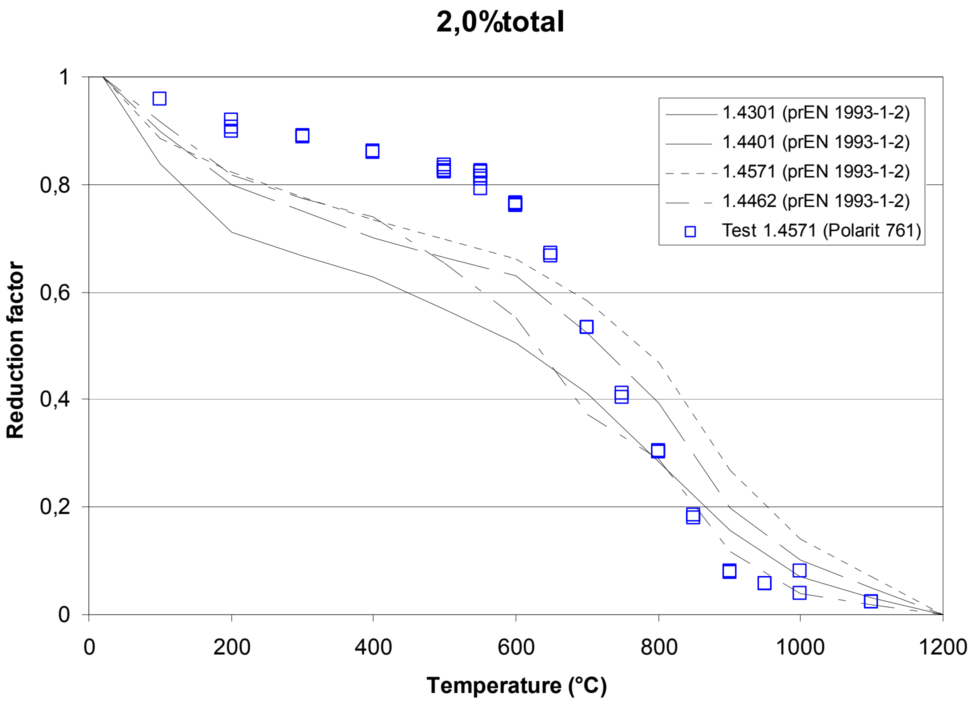


**Figure 3**. Reduction factor of strength at 2.0% total strain of EN 1.4571 (Polarit 761) determined by isothermal tests and compared with values according to prEN 1993-1-2 [1].

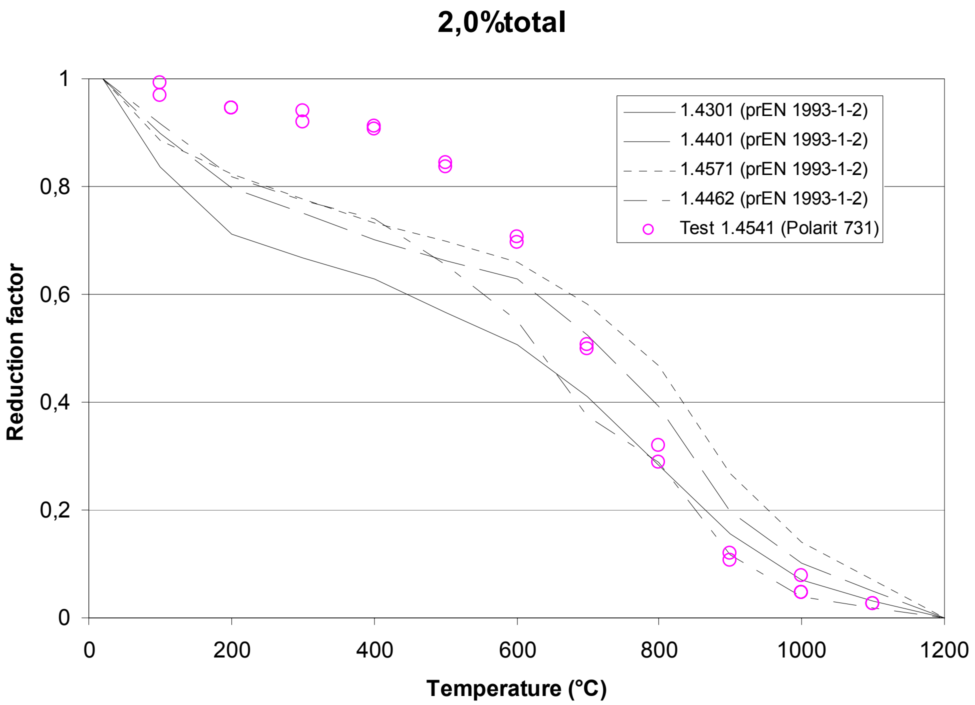


**Figure 4**. Reduction factor of strength at 2.0% total strain of EN 1.4541 (Polarit 731) determined by isothermal tests and compared with values according to prEN 1993-1-2 [1].

In situations which require consideration of the deformation criteria, the strength at a total strain of 1,0%, $f_{1,\theta}$ is recommended as a basis for the calculations instead of $f_{2,\theta}$. The value of $f_{1,\theta}$ should be calculated using the following relationship:

$$f_{1,\theta} = f_{0,2\text{proof},\theta} + 0{,}5 g_{2,\theta}(f_{u,\theta} - f_{0,2\text{proof},\theta}) \qquad (2)$$

Figure 5 compares the measured reduction factors of ultimate strength of materials EN 1.4318 and EN 1.4571 with the reduction factors according to prEN 1993-1-2 [1]. The ultimate strength values are used to determine the reduction factor $k_{2,\theta}$.

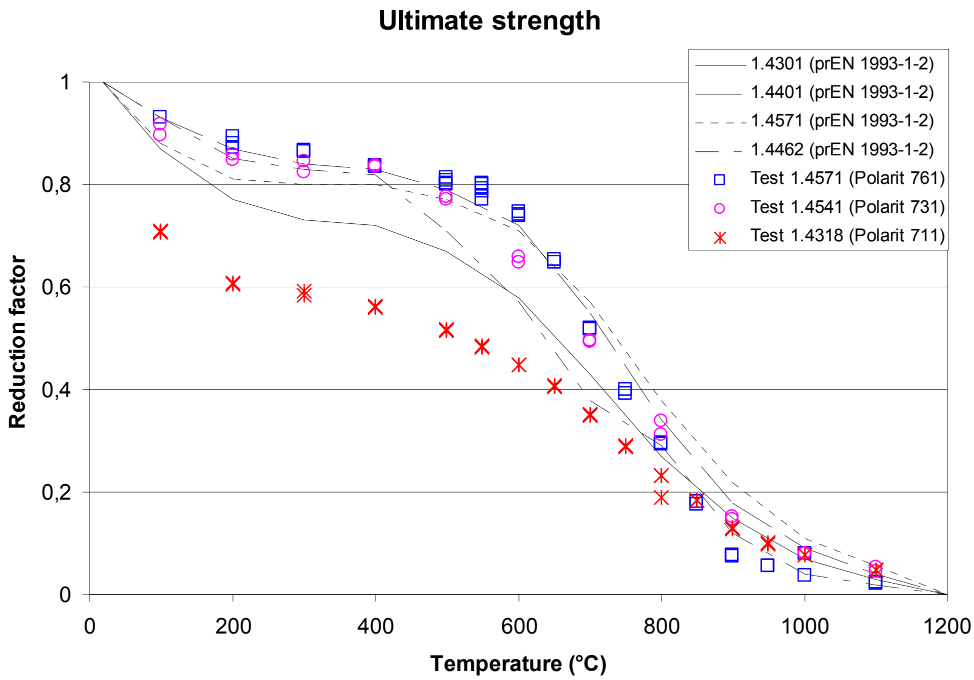


**Figure 5.** Reduction factor of 0.2% proof strength of EN 1.4318 (Polarit 711) and EN 1.4571 (Polarit 761) determined by isothermal tests and compared with values according to prEN 1993-1-2 [1].

The modulus of elasticity is determined based on the initial slope of stress-strain curves. The exact determination of the modulus of elasticity based on the slope of stress-strain curve is very inaccurate, as the proportion limit of austenitic stainless steel is very low. Even the smallest inaccuracy in the measured curves has a very significant influence on the modulus of elasticity, thus the dispersion in values of the modulus of elasticity determined from measured stress-strain curves is quite remarkable. The values of modulus of elasticity determined from steady-state tensile tests of cold-worked material for EN 1.4318 (Polarit 711) and EN 1.4571 (Polarit 761) are shown in Figure 6.

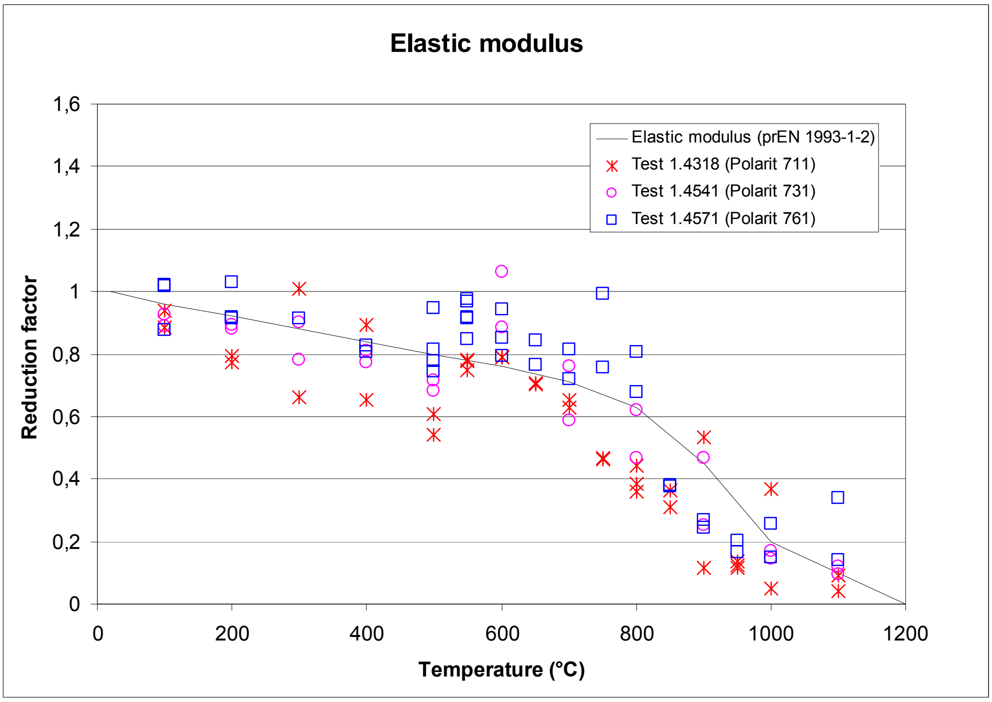


**Figure 6**. Reduction factor of modulus of elasticity of EN 1.4318 (Polarit 711) EN 1.4571 (Polarit 761) and EN 1.4541 (Polarit 731) determined by isothermal tests and compared with values according to prEN 1993-1-2 [1].

## 4 CONCLUSIONS

Stress-strain relationships at elevated temperatures were determined by the steady-state tensile tests for three austenitic stainless steel types EN 1.4318 (Polarit 711) and EN 1.4571 (Polarit 761) and EN 1.4541 (Polarit 731). On the basis of stress-strain curves the stress values in relation to proof strains of 0.1%, 0.2%, 1.0% and 2.0% and to the tensile strength and values of modulus of elasticity were determined. These values were compared with values presented in prEN 1993-1-2 [1]. The following conclusions can be drawn from these comparisons:

- The materials EN 1.4318, EN 1.4571and EN 1.4541 behave in different ways. Therefore it is reasonable to determine the specific reduction factors for each type of stainless steels.
- At temperatures below 600°C relative strength values of materials EN 1.4571 and EN 1.4541 do not decrease as strongly as that of material EN 1.4318 but above 800°C the differences decrease.
- The reduction factor for material EN 1.4571 in prEN 1993-1-2 [1] overestimates the strength values of cold worked material when temperature is above 700°C and underestimates when temperature is below 700°C. For materials EN 1.4318 and EN 1.4541 the reduction factors are not given in prEN 1993-1-2 [1].
- The exact determination of the modulus of elasticity at elevated temperatures is very difficult, as the proportion limit of austenitic stainless steel is very low.

## 5 REFERENCES

[1] prEN 1993-1-2 (Draft February). 2002. Eurocode 3: Design of steel structures, Part 1.2: Structural fire design. Brussels: European Committee for Standardization (CEN). 75 p.

[2] Design Manual for Structural Stainless Steel (second Edition). 2002. The Steel Contruction Institute. 103 p. + app. 61 p.

[3] SFS-EN 10002-5. 1992. Metallin vetokoe. Osa 5.Kuumavetokoe. (Metallic materials. tensile testing. Part 5: Method of testing at elevated temperatures.) Helsinki: Suomen Standardoimisliitto. 35 p.