



## THE INFLUENCE OF TEMPERATURE ON STEEL PERFORMANCE IN RISK MITIGATION SYSTEMS

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### Abstract

Steel, especially high-tensile steel wire, is a core material in flexible risk-mitigation systems such as rockfall barriers and slope stabilization meshes because of its very high tensile strength and energy-absorption capacity. In aggressive or corrosive environments, duplex stainless steels are preferred due to their enhanced corrosion resistance and long-term durability. These systems are often exposed to wildfire risk, where high temperatures can reduce steel strength, increase deformation, and compromise lifetime. The document explains how fire-induced heat affects the mechanical behavior of high-tensile strength and low-alloy steels (typically > 1770 MPa), which are otherwise valued for rigidity, toughness, and performance under extreme loads.

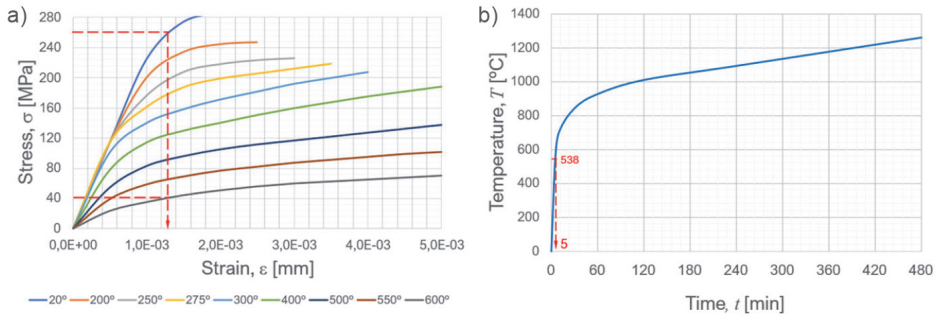
*Keywords: high tensile-strength mesh, influence of high temperature in steel, construction in risk wildfire areas, forest protection*

### 1 Introduction

Risk control and mitigation systems rely heavily on steel, especially high-tensile strength (HT) steel wire, as the primary material for flexible components such as rockfall barriers and slope stabilization systems. Duplex stainless steels (EN 1.4462 | AISI 318) are recommended in highly corrosive environments. These structural systems are commonly installed in mountainous and forested areas, where the risk of wildfires is maximum. Although steel is non-combustible and generally reliable as a structural material, high temperatures generated by fires could degrade its mechanical properties, particularly tensile strength. While steel structures often require limited postfire intervention and can be inspected after exposure. Note that steel gives a false sense of security as it is non-combustible, but its fundamental mechanical properties can be seriously affected by the high temperatures that can be reached during a fire.

### 2 Temperature-related effects on steel profiles

The relationship between stress and deformation is modified with the increase in the temperature of the steel profile. Figure 1a shows how in an A-42 steel profile at a temperature of 600°C, when a stress about 40 MPa is applied, the same strain is achieved for 260 MPa at 20°C. To calculate the strength of fire-resistant of structural elements, specimens are placed in test furnaces and exposed to a fire whose intensity obeys a temperature curve (figure 1b) see ASTM E119 [2].



**Figure 1** a) stress-strain diagram for 420 MPa steel at different temperatures, b) normalized time-temperature curve [1]

The ASTM standardized time–temperature curve (1918), has long served as the basis for fire-resistance testing of structural materials. According to this reference, structural steel can collapse after approximately five minutes when exposed to temperatures around 538°C (figure 1b). Even before collapse, rising temperatures progressively degrade steel’s mechanical properties. In particular, yield strength, which defines the stress level beyond which deformations become permanent, decreases significantly as temperature increases. The document highlights that key mechanical characteristics of structural steel vary with temperature, illustrating how elevated heat leads to reduced strength and stiffness well before complete structural failure occurs.

$K_{y,T} = f_{y,T} / f_y$ : this coefficient expresses the quotient between the yield strength of steel ( $f_{y,T}$ ) for the temperature (T) to be known, and the yield strength of steel at 20°C ( $f_y$ ) (table 1).

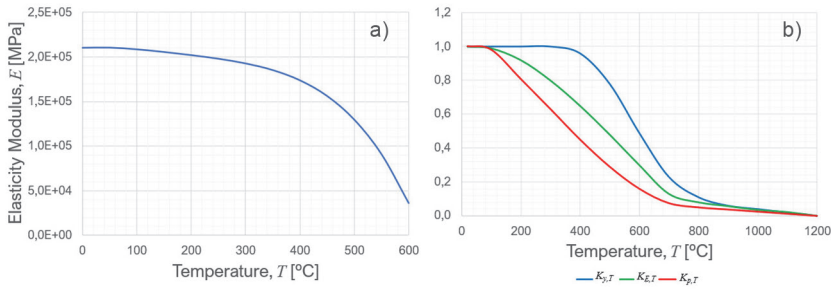
**Table 1** Yield strength  $f_y$  and tensile strength  $f_u$  [MPa]

Steel type	Nominal thickness $t$ [mm]			
	$t \leq 40$		$40 < t \leq 80$	
	$f_y$	$f_u$	$f_y$	$f_u$
S 235	235	360 – 510	215	360 – 510
S 275	275	430 – 580	255	410 – 560
S 355	355	490 – 680	335	470 – 630

$K_{E,T} = E_T / E$ : ratio between the longitudinal modulus of elasticity of the steel or Young’s modulus for the temperature ( $E_T$ ) under study, and the modulus of elasticity of the steel at 20°C ( $E$ ). The conventionally used value for the calculation and design of steel structures in the elastic range is 210, 000 MPa, although its actual value may change according to equation (1) see figure 2a:

$$E = 2,1 \cdot 10^5 \cdot \left( -17,2 \cdot 10^{-12} \cdot T^4 + 11,8 \cdot 10^{-9} \cdot T^3 - 34,5 \cdot 10^{-7} + 15,9 \cdot 10^{-5} \cdot T + 1 \right) \quad (1)$$

$K_{p,T} = f_{p,T} / f_y$ : ratio between the proportionality limit ( $f_{p,T}$ ) for temperature (T) that you want to know, and the yield strength of the steel at 20°C ( $f_y$ ). Figure 2b shows the behaviour of the coefficients that define the mechanical characteristics of structural steels, with the temperature increases.



**Figure 2** a) evolution of the modulus of elasticity with temperature increase, b) variation of some mechanical characteristics of steels with temperature

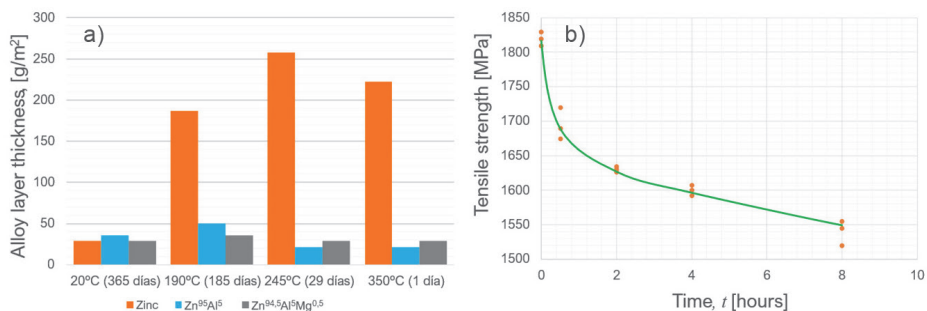
An increase in the temperature of a metal profile is associated with an increase in its length. The thermal linear expansion of steel can be assessed using (2):

$$\delta L = \alpha \cdot \delta \cdot T \cdot L \quad (2)$$

being  $\alpha$  the coefficient of expansion for steel is approximately  $1.2 \cdot 10^{-5}$ . If steel elements are free to expand under heat, significant secondary effects are unlikely. However, when thermal expansion is partially or fully restrained by other structural components, additional stresses can develop. These induced stresses must be considered, as they can contribute to damage or failure even if the steel has not yet lost sufficient strength due to temperature alone. Steel density, it can be stated that it is independent of temperature, with a value of approximately  $7,850 \text{ kg/m}^3$ .

### 3 High tensile strength steel wire to make flexible membranes

Geobrugg manufactures flexible elements for barrier and slope stabilization systems – such as ring nets, spiral nets, and woven rhomboidal meshes - using high-tensile steel wire, typically with tensile strengths exceeding 1770 MPa. These HT or low-alloy steels are valued for their rigidity, high energy absorption capacity, and minimal deformation under load, making them suitable for specialized applications requiring high structural reliability [3]. Low-alloy steels generally contain medium to high carbon levels, which increase strength. Compared to standard carbon steels, low-alloy steels offer superior strength, good resistance to elevated temperatures, and high toughness at low temperatures. High-tensile steel wires, commonly known as music wire (ASTM A228), are typically composed of approximately 0.9% carbon, with small amounts of manganese, sulphur, and phosphorus. Regarding corrosion protection, ZnAl-coated HT steel wires exhibit improved thermal performance compared to pure zinc coatings [4]. While conventional zinc coatings degrade above  $150^\circ\text{C}$  due to the growth of brittle Fe-Zn intermetallic layers, Zn-Al alloy coatings (such as  $\text{Zn}^{95}\text{Al}^5$  and  $\text{Zn}^{94.5}\text{Al}^5\text{Mg}^{0.5}$ ) are more ductile and remain stable at temperatures of up to approximately  $350^\circ\text{C}$ , offering enhanced durability under elevated thermal exposure. Figure 3a shows the thermal stability of the different types of non-ferrous alloy coatings. Zinc–aluminium wire coatings begin to melt at temperatures above  $350^\circ\text{C}$ . At this point, zinc is fully lost and aluminium is partially retained, resulting in a significant reduction in corrosion resistance. Prolonged exposure to very high temperatures ( $730\text{--}1000^\circ\text{C}$ ) can reduce the wire tensile strength to about 50% due to partial transformation into austenite. Even sustained temperatures above  $120^\circ\text{C}$  can negatively affect wire mechanical performance. Tests at  $400^\circ\text{C}$  (figure 3b) show that hightensile strength steel wire retains much of its strength: after 30 minutes, tensile strength drops slightly below 1700 MPa, and after 4 hours it remains around 1600 MPa. Both peak temperature and exposure duration are critical factors in determining the residual tensile strength after fire exposure.



**Figure 3** a) thermal stability for some coating with non-ferrous alloys [4], b) tensile strength with fire duration time at 400°C for HT steel

Forest fires can briefly reach temperatures above 800°C, typically for less than two minutes, after which temperatures drop rapidly as the flame front passes. Although zinc melts at around 350°C, melting mainly affects free zinc near the surface, making significant overall coating loss unlikely. Experience indicates that 3 mm diameter steel wires exposed to wild-firelike conditions generally do not exceed about 430°C. Consequently, during a forest fire, the loss of ZnAl coating mass is expected to be limited, but not critical to the wire’s performance [5].

## 4 Stainless-steel considerations against fire

AISI 304, 316, and 430 stainless steels can withstand short-term exposure to temperatures up to 870°C. At higher temperatures, corrosion, oxidation, and deformation become concerns, making austenitic stainless steels – often alloyed with higher levels of chromium and nickel – the preferred choice for high temperature applications. Grades such as AISI 304, 316, and duplex 318 show good long-term oxidation resistance up to around 800°C and have melting points near 1375°C, temperatures rarely sustained during fires. Fire exposure also affects the surface appearance, causing discoloration, nonprotective oxide layers above 300°C. Short fire exposures may cause sensitization in non-L austenitic grades, while duplex and ferritic steels avoid sensitization but may experience embrittlement around 475°C – typically requiring exposure times longer than those of most fires. Experimental fire tests demonstrate that both austenitic and duplex stainless steel outperform carbon steel and other materials at high temperatures (table 2). In comparative testing at 1000 - 1050°C, aluminium and reinforced fiberglass (GRP) failed in seconds, galvanized carbon steel survived but suffered zinc loss and large deformation, while stainless-steel preserved integrity with significantly lower deflection, even after prolonged high-temperature exposure.

**Table 2** Comparison of test results to various materials

Material	Results	Remarks
Stainless steel (low carbon)	Maintains integrity 5 min until end 45 min [80.5 mm]	Average temperature 707°C and maximum 757°C.
Galvanized carbon steel	Maintains integrity 5 min [166.5 mm]	Zinc dripping coating, maximum temperature 642°C
Aluminium	Immediate collapse 26 sec	Outside the monitoring area
Fiberglass	Immediate collapse 30 sec	Gas and smoke emission

Stainless steel retains its mechanical properties better than carbon steel. Above 200°C, the reduction in Young's modulus is significantly lower for stainless steel; at 600°C, stainless steel retains about 75% of its stiffness, compared to only 30% for carbon steel (figure 4). This results in less than half the deflection under the same load. Overall, stainless steel shows superior performance at elevated temperatures compared to carbon steel and aluminium.

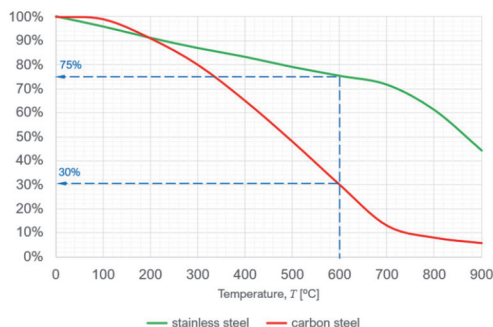


Figure 4 Comparison between stainless steel and carbon steel ( $K_{E,T}$  with temperature T)

## 5 Case study: slope stabilization, Hattingen, Germany

During the summer of 2019, a fire broke out on a previously stabilized slope on Königsteiner, Hattingen, affecting a large part of the surface [6]. The stabilization system was composed of a HT TECCO® G65/3 mesh with Zn<sup>95</sup>Al<sup>5</sup> Class B coating and Gewi bar nails of 28 mm in diameter every 9 m<sup>2</sup>. The presence of a specialist in the field was required to study the consequences and propose solutions. The final state of the slope after the event is observed in figure 5a and the inspection process carried out using a lifting basket (figure 5b). Post-fire inspections showed no significant visible damage. To assess potential thermal effects more thoroughly, insitu samples of the HT wire exposed to the fire were collected and tested for residual tensile strength and coating corrosion protection (figure 6b).

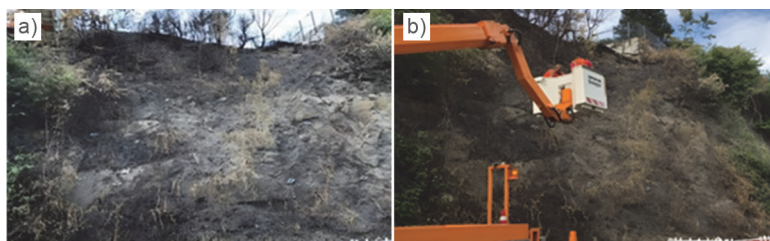


Figure 5 a) state of the slope, once the fire has passed, b) slope inspection process

Test results indicated that the corrosion protection remained in good condition and residual tensile strength was largely unaffected. Only one sample showed reduced strength (table 3), likely due to localized heat concentration, suggesting that replacement of the affected membrane section may be enough.

In forest fire scenarios, corrosion protection typically requires closer attention than residual tensile strength. See detail of the surface condition (figure 6b).

**Table 3** Results of the tensile strength tests carried out on the samples

No.	Coating	Measured diameter	Theoretical diameter	Breaking load	Tensile strength
	[g/m <sup>2</sup> ]	[mm]	[mm]	[kN]	[MPa]
1 <sup>a</sup>	357 <sup>b</sup>	3.07	3.00	10.39	1470.5
2 <sup>a</sup>	202	3.00	3.00	12.59	1782.5
3 <sup>a</sup>	184	3.02	3.00	6.26	885.1
4 <sup>a</sup>	214	3.00	3.00	11.95	1690.8
5 <sup>a</sup>	189	3.01	3.00	13.76	1946.8

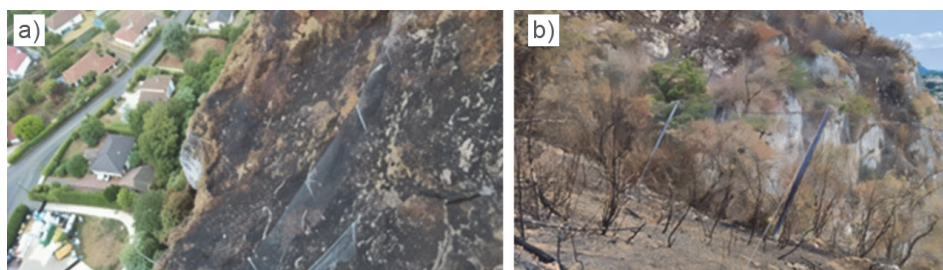
<sup>a</sup> sample 1, 2 and 3 collected at slope top above the top rope; samples 5 and 6 were collected at the slope bottom, below the lower perimeter rope (figure 6a)  
<sup>b</sup> the wire has strong charring on the surface, which could distort the measurement result



**Figure 6** a) detail of the upper part of the membrane after the fire passed, b) wire surface condition in some areas of the mesh after the fire

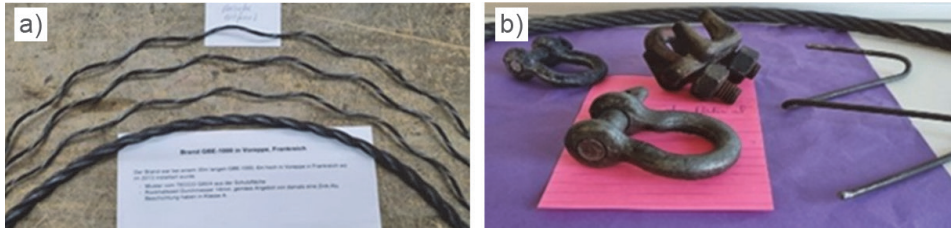
## 6 Case study: rockfall protection, Voreppe, France

This case study deals with a rockfall protection barrier type GBE-1000A of 1000 kJ energy absorption, 30 m in length long and 6 m in height, installed in 2013 in the Rhône Alpes region of Grenoble, France [6]. In the summer of 2022, a forest fire broke out that affected the area where the barrier was located (figure 7a) and, as in the previous case, it was necessary for a specialist to travel to the site to take samples of some of the elements subjected to temperature changes and evaluate their condition. As can be seen in figure 7b, the elements that suffered the most were those located in the lower half of the barrier height.



**Figure 7** a) top view of the site after the fire (2022), b) back view where the height reached by the flames can be seen

Samples were taken of both the interposition mesh 4 mm wire Zn<sup>95</sup>Al<sup>5</sup> class B coating (figure 8b), and strands of the 14 mm retaining rope (DIN 3060, figure 8a), with same type of coating and mesh, shackles and wire rope clips (figure 8b).



**Figure 8** a) retaining ropes strands under analysis, b) sample of tested accessories, cables and mesh

In 6 samples (outer strands) taken from the 14 mm rope, the coating weight values were between 143 - 164 g/m<sup>2</sup> (table 4), below the 165 g/m<sup>2</sup> (EN 10244-2) standard. Then ropes in this area must be replaced due to loss of corrosion protection. In addition, the residual tensile strength values are in between 1709 - 1773 MPa (table 4), close to the 1770MPa (nominal value).

**Table 4** Coating and tensile strength tests carried out rope strands

No.	Diameter [mm]	Length [mm]	Dectcion [mm <sup>2</sup> ]	Coating [g/m <sup>2</sup> ]	Breaking load [N]	Fy [MPa]
1	1.12	150	0.985	148	1702.4	1728.3
2	1.12	150	0.985	144	1683.7	1709.3
3	1.11	150	0.968	143	1716.4	1773.1
4	1.12	150	0.985	146	1724.6	1750.9
5	1.12	150	0.985	164	1688.9	1714.6
6	1.12	150	0.985	155	1689.6	1715.3

This means that while the rope has asked for its corrosion protection capability, the residual tensile strength is kept in an acceptable order. Given the uniformity in the surface, for the evaluation only a 4 mm wire sample was taken, the weight of the coating was measured (table 5) obtaining a value of 152 g/m<sup>2</sup>, which practically coincides with the value established in the EN 10244-2 standard for 4 mm wire diameter (150 g/m<sup>2</sup>). It can be concluded that in principle the mesh of this barrier does not require replacement, if it is considered only in anticorrosive coating. The residual tensile strength obtained for the wire constituting the mesh is 1412.90 MPa (table 5), which is below the nominal value of 1770 MPa by more than 20%.

**Table 5** Coating and tensile strength tests to the mesh

No.	Diameter [mm]	Length [mm]	Section [mm <sup>2</sup> ]	Coating [g/m <sup>2</sup> ]	Breaking load [N]	Fy [MPa]
1	4.04	50	0.985	152	17755.14	1412.90

Since the residual tensile strength has fallen in an unacceptable order, the customer decided to replace the membrane. In this example it was not necessary to evaluate the profiles of the post, from the field visit (visual inspection) it was concluded that the temperature values achieved during the fire were relatively low and it was considered that the resistant and corrosion protection properties of these were not compromised. The aesthetic, perhaps, is questionable.

## 7 Conclusion

Steel is non-combustible, but the increase in its temperature means significant losses in its mechanical capacity. In contrast, critical load is the load that a structural element can withstand at a certain temperature and according to the table of mechanical capacities that it presents at that temperature. Cooled steel recovers much of its initial strength, and in many cases the impossibility of correcting deformations is the determining factor of waste. Fire tests and the study of life cycle costs together demonstrate that high-tensile strength and stainless steel are cost-effective materials that offer a higher degree of safety than GRP, aluminium or mild steel (galvanized or painted). Compared to mild steel, lightweight stainless-steel structures reduce the weight, improve fire resistance, and virtually eliminate the need for maintenance. After analyzing test results, we can conclude that stainless steel lasts much longer and, therefore, is safer when installing it in mitigation structures.

## References

- [1] Gonzalez, S.: NTP 200: Estructuras metálicas: comportamiento frente al fuego (I), Madrid, 2008., <https://www.insst.es/>
- [2] ASTM E119-20: Standard Test Methods for Fire Tests of Building Construction and Materials, Pennsylvania, 2020.
- [3] Luis-Fonseca, R.: Aplicación de membranas flexibles para la prevención de riesgos naturales, Ropero, Madrid, 2010.
- [4] Bekaert: Bezinal® 3000 coated wire for cables and ropes, Brussels, 2017.
- [5] Bennetts, I.D., Thomas, I.R.: Developments in the design of buildings for fire safety, Australasian Structural Engineering Conference (ASEC94), pp. 640-645, Sydney, 1994.
- [6] Roduner, A.: Estimation and determination of the remaining service lifetime using case studies, Consis, Walenstadt, 2023.