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Research paper

Experimental study on post fire mechanical properties exhibited by S235JR and S355J2+N steel grades

Piotr Woźniczka[1], **Paulina Zajdel**[2]

Abstract: The results of research on mechanical properties exhibited by typical structural steel grades S235 and S355 are presented in this paper. Each time the samples had been heated up to a predetermined temperature, cooled and subjected to a static tensile strength test. Several fire development scenarios and sample cooling scenarios had been considered. The maximum heating temperature reached during the research remained between 400°C and 800°C. The results of own experimental research have been compared against the recommendations found in bibliography regarding the reduction degree of mechanical properties exhibited by steel. The changes in the values of such parameters as the yield limit, tensile strength, modulus of elasticity and total limit elongation have been considered in the conducted analyses. Based on the results of this research new, temperature dependent, values of reduction coefficients for mechanical parameters of steel exhibited post fire have been determined. Two computational approaches have been applied for this purpose. In the first approach the reduction coefficients have been determined based on the minimum values obtained experimentally. In the second approach the characteristic and design values have been derived following the recommendations of the standard PN EN 1990. Both proposed sets of reduction coefficients may be applied when assessing the technical condition of a structure following a fire incident.

Keywords: carbon steel, post-fire properties, reduction factor, steel structures, fire, steel

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1. Introduction

In the case of fire buildings and structural elements of buildings are exposed to the action of high temperature [1,2]. For steel structures, which have survived a fire an action of this type may result not only in significant damage or substantial deformations of particular components [3] but also in the changes of steel microstructure. As a result, after fire the material used to make the structure is also characterized by changed mechanical properties [4, 5]. Deterioration of plastic properties exhibited by the affected material is a typical example here. This results in an increased hardness and impact strength [6, 7]. These changes are observed not only in the case of elements made of steel but also in the case of bolts [8]. It has to be made clear here, that besides the highest temperature reached during the fire, the heating intensity, duration of fire and the speed and mode of cooling have an influence as well [9–11]. Thus a reliable assessment of the technical condition exhibited by steel structure after surviving a fire incident should encompass both an inventory of permanent deformations and displacements incurred [12] and evaluation of permanent changes in mechanical properties such as yield limit, tensile strength, impact strength and modulus of elasticity [13, 14].

The building codes currently in force are oriented mostly on the behaviour of steel structures under conditions of fire action [15], without yielding any guidelines regarding post fire evaluation of material properties. Therefore in practice the values of reduction coefficients for particular parameters may be determined only based on the results of tests performed on elements of given structure or guidelines found in bibliography [16]. Sample results of tests on strength parameters exhibited by steel after surviving a fire incident including recommended values of reduction parameters are for example listed in [17–22]. Analogous results for cold formed steel and high strength steels are presented in [23, 24] and [25–31], respectively. It has to be noted here, that the reduction coefficients used to estimate the post fire values of steel mechanical properties are usually determined using two approaches. In the first, simplified approach (applied among others in [18]) values of these coefficients are determined based on the minimum values of given strength parameter. In the second, more complex approach ([19, 20]) the so called retention coefficients have been introduced, understood as a product of code coefficient for fire conditions ($k_{y,\theta}$, $k_{u,\theta}$, $k_{\varepsilon u,\theta}$, $k_{E,\theta}$ respectively according to [15]) and a corresponding recovery factor ($r_{y,\theta}$, $r_{u,\theta}$, $r_{\varepsilon u,\theta}$, $r_{E,\theta}$ respectively according to [19]). The recovery factor is interpreted as a quotient of given parameter after fire and reduced value determined during the fire. In this approach the partial coefficients determined following [32] are accounted for as well.

Therefore the results of own experimental research on mechanical properties of steel exhibited post fire are presented in this paper. Samples made of the two basic structural steel grades used in Poland, that is S235JR and S355J2+N have been subjected to the static tensile test. The obtained results have been compared against the values of reduction coefficients recommended in [18] and [20]. Based on the results of the conducted research a modification of the relationships recommended in bibliography for the yield limit, tensile strength, linear modulus of elasticity and ultimate strain reduction coefficients for S235 and S355 steel grades have been recommended. The two above described methods for preparing these coefficients have been applied. In the first method the coefficients were determined based on the minimum values, while in the second approach design and characteristic values have been implemented following the recommendations of the standard [32].

2. Experimental research

The tests of mechanical properties exhibited by the S235JR steel grade have been conducted on samples cut from three full sized steel girders subjected to simulated fire action. These girders were subjected to an assumed load level, and subsequently heated by ceramic heating mats until loosing stability [33–35]. After testing and cooling of elements 12 mm thick samples have been extracted from the flange of each girder while 4 mm thick samples were extracted from the webs. The plates used to make the samples (following [36]) have been cut (Fig. 1) in such a manner as to coincide with the location of thermocouples registering the changes in the temperature during the full scale tests. The highest temperature reached during the heating process remained in between 480°C and 632°C. The temperature vs. time curves corresponding to particular girders and respective plate thicknesses are depicted on Fig. 2. For plates 12 mm thick 6 samples have been extracted of each girder, while for plates 4 mm thick 10 samples have been extracted of each girder. Thus altogether 48 samples have been made for the S235JR steel grade.

(a) (b)

Fig. 1. Sections of girders made of S235JR steel cut for further testing:
a) plate 4 mm thick, b) plate 12 mm thick

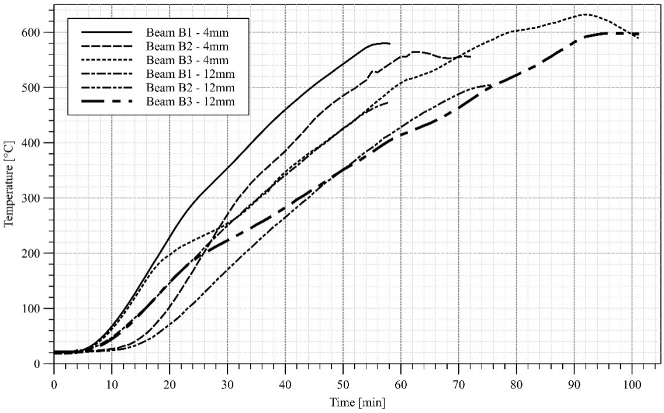
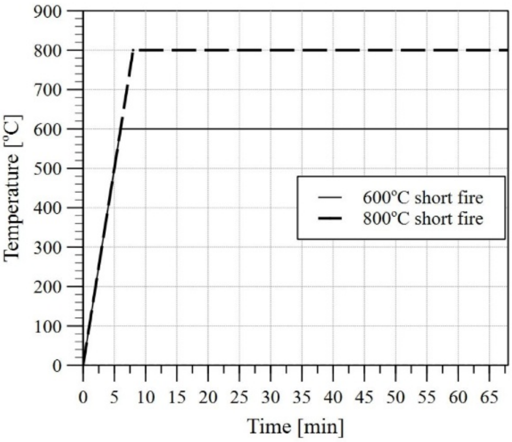


Fig. 2. Heating curves for plates 4 mm and 12 mm thick made of S235JR steel grade

The tests of the mechanical properties exhibited by the S355J2+N steel grade post fire have been conducted on samples having shape and dimensions conforming to the requirements set in [36] as well (Fig. 3). Prior to testing the samples have been subjected to the heating simulating fire action. Two maximum values of the heating temperature have been applied, that is 600°C and 800°C, and heating time reached one hour (simulation of a "short" fire) or alternatively ten hours (simulation of a "long" fire). The heating process took place in a laboratory muffle furnace following the temperature – time curve depicted on Fig. 4. The heating temperature levels have been intentionally selected for analysis as values below and above the eutectoid transformation temperature resulting in permanent changes in the microstructure of steel [4, 37]. The samples differed in the post fire cooling mode applied. A simulation of firefighting action has been considered with samples rapidly cooled in water mist and simulation of self-extinguishing of the fire by slow cooling in the laboratory furnace. The static tensile test has been performed on nine samples, including one reference sample not subjected to the action of high temperature.

Fig. 3. Selected samples made of the S355J2+N steel grade after simulated fire action



(a)

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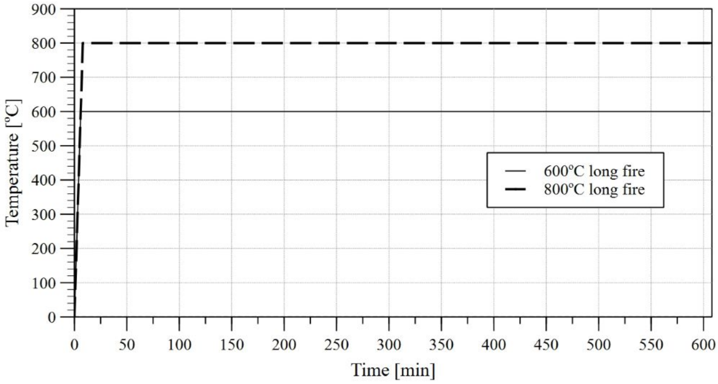


(b)

Fig. 4. Heating curves of samples made of S355J2+N steel grade:
a) simulation of a "short" fire, b) simulation of a "long" fire

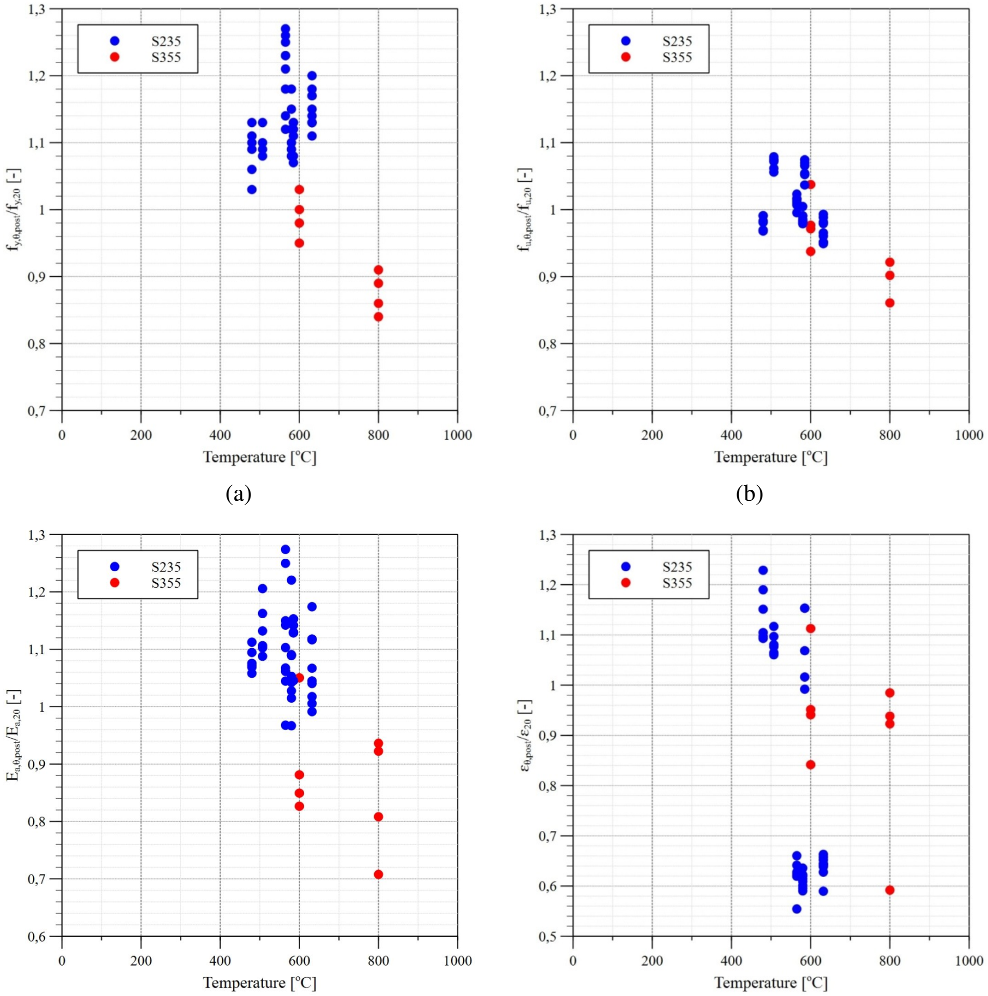
The static tensile test on these samples has been performed using the class 0.5 WDW-300E testing machine capable of exerting 300 kN tensile force. An extensometer with 25 mm long measurement base has been applied during the tests. The tensile test was automatically registered by a computer program, which was applied to generate the load vs. time, load vs. extension and load vs. displacement graphs.

3. The results and discussion thereof

3.1. Results of the experimental tests

The results of the static tensile strength test for samples cooled after simulated fire action have been shown as a ratio of the value of given parameter after fire to the value of the same parameter in the initial state (Fig. 5). The results are differentiated regarding the tested steel grade and refer to the maximum heating temperature applied. Properties determined for the steel after fire are denoted by the symbols with subscript "θ, post", while analogous values measured at room temperature on samples not affected by simulated fire action are indicated by subscript "20". The results of mechanical properties tests for S235JR steel at room temperature are presented in [33].

As may be observed on data juxtaposed on Fig. 5, for samples made of S235JR steel grade the yield limit determined after fire ($f_{y,\theta,\text{post}}$) in general increased, sometimes even significantly. This in particular pertains to the case of heating temperature close to 600°C. For this steel grade the reduction in tensile strength ($f_{u,\theta,\text{post}}$) and the modulus of elasticity ($E_{a,\theta,\text{post}}$) in most of the tested cases did not occur or was insignificant when compared against initial values. However, on the graph pertaining to the limit elongation ($\varepsilon_{\theta,\text{post}}$), significant decrease in plastic properties of S235JR steel may be observed post fire. The decrease in limit elongation by about 40% was observed on most of the samples heated up to 600°C. In the case of S355J2+N steel the analogous level of decrease was observed on a single sample heated to the maximum temperature of 800°C. In all the remaining cases the S355J2+N steel was characterized by much better plastic properties when compared against the S235JR steel. At the same time the samples made of S355J2+N steel exhibited highest reduction in the remaining parameters such as the yield limit, tensile strength or the modulus of elasticity. As expected, the degree of reduction each time increased with increased heating temperature.



(a) (b)

(c) (d)

Fig. 5. Mechanical properties of steel after a fire incident vs. in as manufactured state: a) yield limit, b) tensile strength, c) modulus of elasticity, d) limit elongation (at destruction)

3.2. Reduction coefficients estimated based on the minimum values

For the considered samples the reduction degree of the yield limit, tensile strength, modulus of elasticity and the limit elongation has been compared on Fig. 6 against the analogous values proposed in [18] (unalloyed steels, alloyed steels and high strength steels) and [20] (carbon steels). It should be noted, that in the case of changes in the yield limit and the tensile strength a more conservative approach is presented in [20]. At the same time the assumptions presented in [18] are more conservative with respect to the forecast value of the modulus of elasticity. However, the results of our experimental research to a significant degree diverge from the recommendations presented in bibliography. In the case of many samples application of recommendations listed in [18] and [20] leads to grossly overestimated values of the parameters such as the tensile strength, modulus of elasticity or limit elongation. Regarding the yield limit analogous overestimates are visible only for temperature remaining at about 600°C. It should be noted, that this level of temperature should not result in permanent structural changes in steel. In spite of that, as indicated by the data depicted on Fig. 5 and Fig. 6 many samples heated up to 600°C exhibited not only an insignificant reduction in the yield limit but also a significant reduction in the modulus of elasticity.

Under those circumstances, based on the observations presented above a modification of the formulae listed in [18] and [20] to determine the reduction level of particular mechanical properties of steel has been proposed. The proposed modified equations are presented below:

$$k_{y,\theta,\text{post}} = \frac{f_{y,\theta,\text{post}}}{f_{y,20}} = \begin{cases} 1 & \theta_a \leq 500^\circ\text{C} \\ 1.315 - \theta_a/1588 & 500^\circ\text{C} < \theta_a < 900^\circ\text{C} \\ 0.748 & \theta_a \geq 900^\circ\text{C} \end{cases} \tag{3.1}$$

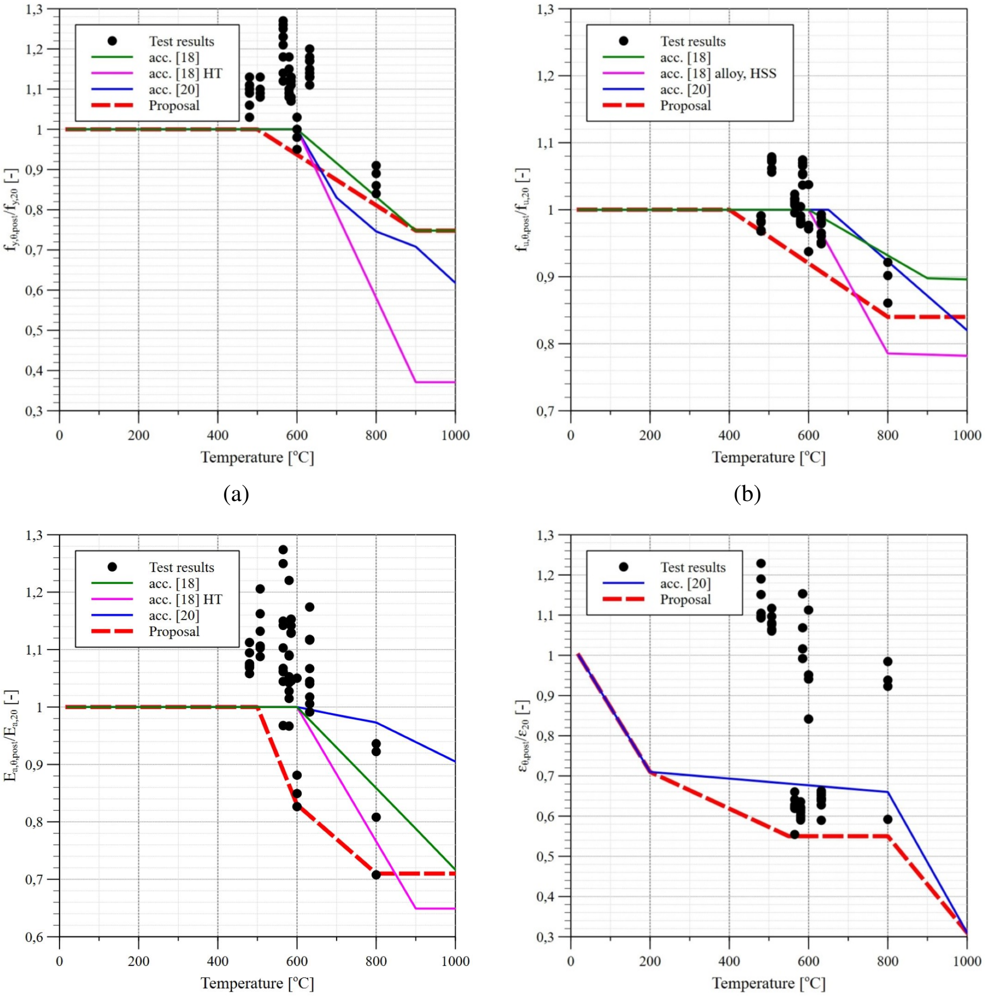
$$k_{u,\theta,\text{post}} = \frac{f_{u,\theta,\text{post}}}{f_{u,20}} = \begin{cases} 1 & \theta_a \leq 400^\circ\text{C} \\ 1.160 - \theta_a/2500 & 400^\circ\text{C} < \theta_a < 800^\circ\text{C} \\ 0.840 & \theta_a \geq 800^\circ\text{C} \end{cases} \tag{3.2}$$

$$k_{E,\theta,\text{post}} = \frac{E_{a,\theta,\text{post}}}{E_{a,20}} = \begin{cases} 1 & \theta_a \leq 400^\circ\text{C} \\ 1.340 - \theta_a/1177 & 400^\circ\text{C} < \theta_a < 600^\circ\text{C} \\ 1.190 - \theta_a/1665 & 600^\circ\text{C} \leq \theta_a < 800^\circ\text{C} \\ 0.710 & \theta_a \geq 800^\circ\text{C} \end{cases} \tag{3.3}$$

$$k_{\varepsilon,\theta,\text{post}} = \frac{\varepsilon_{\theta,\text{post}}}{\varepsilon_{20}} = \begin{cases} 1.033 - \theta_a/600 & \theta_a \leq 200^\circ\text{C} \\ 0.785 - \theta_a/2340 & 200^\circ\text{C} < \theta_a < 550^\circ\text{C} \\ 0.550 & 550^\circ\text{C} \leq \theta_a < 800^\circ\text{C} \\ 1.510 - \theta_a/833 & \theta_a \geq 800^\circ\text{C} \end{cases} \tag{3.4}$$

where: $k_{y,\theta,\text{post}}$; $k_{u,\theta,\text{post}}$; $k_{E,\theta,\text{post}}$; $k_{\varepsilon,\theta,\text{post}}$ – values of the reduction coefficients for the yield limit, tensile strength, modulus of elasticity and limit elongation, respectively, θ_a – maximum temperature reached during heating, $f_{y,20}$; $f_{y,\theta,\text{post}}$ – yield limit of steel before and after the fire, $f_{u,20}$; $f_{u,\theta,\text{post}}$ – tensile strength of steel before and after the fire, $E_{a,20}$; $E_{a,\theta,\text{post}}$ – modulus of elasticity of steel before and after the fire, ε_{20}; $\varepsilon_{\theta,\text{post}}$ – limit elongation of steel before and after the fire.

The proposed curves defined by the above formulae (in red – Fig. 6) have been determined based on the minimum value of the ratio of given parameter after the fire to the value of the same parameter prior to the fire. These relationships constitute a safe lower estimate of basic steel parameters after fire, determined during a static tensile test. The curves have been modified for the temperature range of 400–800°C, as analysed during our research. For the temperatures below 400°C and above 800°C, the curves have been fitted to conform to the recommendations listed in [18] and [20], as our results did not cover these temperature ranges.



(a) (b)

(c) (d)

Fig. 6. Proposed relationships for the reduction coefficients regarding material properties of steel exhibited post fire compared against the recommendations found in [18, 20]: a) yield limit, b) tensile strength, c) modulus of elasticity, d) limit elongation. HT – heat-treated; HSS – high strength steel

3.3. Reduction coefficients determined taking into account the recommendations of PN-EN 1990

Values of the reduction coefficients presented so far are based on the minimum values of given parameter related to the initial value of said parameter determined experimentally at room temperature. Application of the so estimated coefficients to the characteristic or design value of the steel strength parameter listed in the standard is safe and at the same time relatively simple in practical application. However, it should be noted, that the bearing capacity analysis of a structure in persistent design scenario (including the case of a survived fire incident) should be each time conducted based on the characteristic and design values determined conforming to the standard [32]. Therefore the analyses oriented on the determination of characteristic and design values of the yield limit and tensile strength exhibited by the steel had been performed as well. The available results of own experimental research have been subdivided into appropriate series. The steel grade (S235 or S355, respectively) and the maximum sample heating temperature have been used as the subdivision criteria. For each thus defined group its size (number of samples assigned), mean value and the coefficient of variation have been determined (Table 1 and Table 2).

Table 1. Statistical data for S235 and S355 steels – yield limit $f_{y,\theta,\text{post}}$

Steel grade	**Temperature [°C]**	**Number of samples – n**	**Mean value – μ [MPa]**	**Standard deviation – σ [MPa]**	**Coefficient of variation – ν [%]**
S235	408–507	12	300.1	11.0	3.7
S235	562–632	36	336.3	17.7	5.2
S355	600	4	379.0	13.3	3.5
S355	800	4	334.5	11.9	3.6

Table 2. Statistical data for S235 and S355 steels – tensile strength of steel $f_{u,\theta,\text{post}}$

Steel grade	**Temperature [°C]**	**Number of samples – n**	**Mean value – μ [MPa]**	**Standard deviation – σ [MPa]**	**Coefficient of variation – ν [%]**
S235	408–507	12	439.2	18.7	4.3
S235	562–632	36	430.7	13.3	3.1
S355	600	4	549.3	23.3	4.2
S355	800	3	501.0	17.3	3.5

The data juxtaposed in the Table 1 and Table 2 indicate that the obtained results are characterized by very low values of coefficients of variation, remaining between 3.5% and 4.3%. It has to be noted here that one set of results obtained for the S355 steel heated up to 800°C, subsequently cooled and tested for strength has been removed from the set, as a clearly overstated result has been obtained for $f_{u,\theta,\text{post}}$. This value significantly deviated from the other results and from the data available in the bibliography. When computing the characteristic and design values the annexes D7.2 and D7.3 to the standard [32] have been used. Taking into account the availability of voluminous data obtained by other researchers [20], it was decided to apply the case "$V_{x\,\text{known}}$". For the yield limit the coefficients of variation determined for the results obtained during our research were lower than the ones determined over more numerous samples. Therefore it was decided to apply the coefficient of variation given in [20], having the value of 12%. At the same time during the strength analysis of post fire samples one should take into account the initial value of the coefficient of variation for given material property exhibited before the action of high temperature. An appropriate value of the coefficient of variation for standard structural steel at the room temperature may be assumed as equal to 7% [20, 38]. Finally, in the following calculations the value of the coefficient of variation has been determined by the following Eq. (3.5):

$$V_{\text{app}}^2 = V_{\text{post.fire}}^2 - V_{\text{amb}}^2 \tag{3.5}$$

where: $V_{\text{app}}; V_{\text{post.fire}}; V_{\text{amb}}$ – coefficients of variation exhibited by the yield limit applied to determine the characteristic and design values, assumed as equal to 12% for post fire steel and 7% for the steel at room temperature.

For $f_{u,\theta,\text{post}}$ a value of 4.3% has been assumed for the coefficient of variation, based on the results of our own experimental research. This value is higher than the analogous one listed in bibliography [20] and almost equal to the value of the coefficient of variation for steel at room temperature prior to the action of high temperature. Under such circumstances no reduction analogous to that described by the relationship (3.5) was applied. The characteristic and design values of particular parameters determined finally are juxtaposed in the Tables 3 and 4. Tables 4 and 5 contain the values of reduction and partial coefficients suggested for the computational approach proposed here. These values have been calculated under assumption that the characteristic and design values applied at the stage of an expert assessment are defined by the Eq. (3.6) and Eq. (3.7). Design values determined by application of Eq. (3.6) and Eq. (3.7) with proposed coefficients for characteristic and design values computed following the prescriptions of the standard [32] (Table 3 and Table 4) are listed in the Tables 5 and 6 as well. As may be seen, the proposed coefficients allow for sufficiently accurate and safe estimation of both of these parameters, at the same time allowing to conduct the calculations in conformity with general assumptions of the standard [39].

$$X_{k.\text{post.fire}} = k_{\text{red}} \cdot X_{k.\text{ambient}} \tag{3.6}$$

$$X_{d.\text{post.fire}} = k_{\text{red}} \cdot \frac{X_{k.\text{ambient}}}{\gamma_{m.\text{post.fire}}} \tag{3.7}$$

where: $X_{k.\text{post.fire}}$ – characteristic value of a strength parameter after the fire, $X_{d.\text{post.fire}}$ – design value of a strength parameter after the fire, k_{red}, $\gamma_{m.\text{post.fire}}$ – reduction coefficient and partial factor depending on the temperature range and considered parameter, juxtaposed in the Table 5 and Table 6.

Table 3. Characteristic and design values of the yield limit $f_{y,\theta,\text{post}}$ for S235 and S355 steel grades depending on the maximum temperature reached during the fire

Steel grade	**Temperature [°C]**	***EN* – standard value [MPa] acc. [39]**	**$X_{k.\text{test}}$ – characteristic value [MPa]**	**$X_{d.\text{test}}$ – design value [MPa]**	**$X_{k.\text{test}}$ / *EN***	**$X_{d.\text{test}}$ / *EN***
S235	408–507	235	249.8	205.6	1.06	0.87
S235	562–632	235	281.5	233.7	1.20	0.99
S355	600	355	311.4	251.9	0.88	0.71
S355	800	355	274.8	222.4	0.77	0.63

Table 4. Characteristic and design values of the tensile strength $f_{u,\theta,\text{post}}$ for S235 and S355 steel grades depending on the maximum temperature reached during the fire

Steel grade	**Temperature [°C]**	***EN* – standard value [MPa] acc. [39]**	**$X_{k.\text{test}}$ – characteristic value [MPa]**	**$X_{d.\text{test}}$ – design value [MPa]**	**$X_{k.\text{test}}$ / EN**	**$X_{d.\text{test}}$ / *EN***
S235	408–507	360	406.7	378.2	1.13	1.05
S235	562–632	360	399.8	372.7	1.11	1.04
S355	600	490	506.0	468.0	1.03	0.96
S355	800	490	460.3	424.3	0.94	0.87

Table 5. Proposed reduction coefficients and partial coefficients for the yield limit $f_{y,\theta,\text{post}}$ – steel grades S235 and S355

Steel grade	**Temperature [°C]**	**$k_{\text{red}} = k_{y,\theta,\text{ post}}$**	**$\gamma_{m.\text{post.fire}}$**	**X_k acc. (3.6) / $X_{k.\text{test}}$**	**X_d acc. (3.7) / $X_{d.\text{test}}$**
S235	408–507	1.0	1.1	0.94	1.04
S235	562–632	1.0	1.1	0.83	0.91
S355	600	0.9	1.2	0.97	1.00
S355	800	0.8	1.2	0.97	1.00

Table 6. Proposed reduction coefficients and partial coefficients for the tensile strength $f_{u,\theta,\text{post}}$ – steel grades S235 and S355

Steel grade	**Temperature [°C]**	**$k_{\text{red}} = k_{u,\theta,\text{ post}}$**	**$\gamma_{m.\text{post.fire}}$**	**X_k acc. (3.6) / $X_{k.\text{test}}$**	**X_d acc. (3.7) / $X_{d.\text{test}}$**
S235	408–507	1.0	1.0	0.89	0.95
S235	562–632	1.0	1.0	0.90	0.97
S355	600	1.0	1.05	0.97	1.00
S355	800	0.9	1.05	0.96	0.99

3.4. Comparison of steel parameters estimated using proposed coefficients

Table 7 contains a comparison of the yield limit and tensile strength, which should be applied during calculations following the guidelines described in the Section 3.2 (Eq. (3.1) and Eq. (3.2)) and based on the method described in the Section 3.3 (Eq. (3.7), Tables 5 and 6). These values have been determined for the maximum steel temperatures considered during our research, that is 500°C, 600°C for the S235 steel grade and 600°C, 800°C for the S355 steel grade. The data juxtaposed in the Table 7 indicate that both methods in the most of the cases considered lead to similar results. More substantial differences have been observed only in the case of the yield limit determined for the S355 steel grade. At the same time both methods represent a safe estimate with respect to other methods available in current bibliography.

Table 7. Comparison of the yield limit and tensile strength applied in calculations and determined based on the Eq. (3.1) and Eq. (3.2) through Eq. (3.7)

Steel grade	**Temperature [°C]**	$f_{y,\theta,\text{post}}$			$f_{u,\theta,\text{post}}$		
		Eq. (3.1)	**Eq. (3.7)**	**Eq. (3.1)/ Eq. (3.7)**	**Eq. (3.2)**	**Eq. (3.7)**	**Eq. (3.2)/ Eq. (3.7)**
S235	500	235.0	213.6	1.10	345.6	360.0	0.96
S235	600	220.2	213.6	1.03	331.2	360.0	0.92
S355	600	332.6	266.3	1.25	450.8	466.7	0.96
S355	800	287.9	236.7	1.22	401.8	420.0	0.96

4. Conclusions

The results of our own experimental research on estimation of mechanical parameters exhibited by steel after surviving a fire incident are presented here. Two typical steel grades have been considered, and the range of temperature applied to the samples remained between approximately 400°C through 800°C. Based on the conducted experiments new values of the reduction coefficients have been determined, allowing to estimate the parameters such as the yield limit, tensile strength, modulus of elasticity and limit elongation depending on the maximum temperature. These coefficients have been determined using two approaches based on the minimum values or following the calculations conforming to the provisions of the standard PN EN 1990 [32].

As there are no recommendations in the standards currently in force the proposed values of reduction coefficients may constitute an important guide for the designers conducting appraisals of structures, which have survived fire incidents. At the same time both methods present a safe estimate when compared against other methods proposed in bibliography, which may be used to determine the values of steel mechanical coefficients after a fire incident.

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Badania po-pożarowych właściwości mechanicznych stali S235JR i S355J2+N

Słowa kluczowe: konstrukcje stalowe, pożar, stal, stal węglowa, właściwości po-pożarowe, współczynnik redukcyjny

Streszczenie:

Przedstawiono wyniki badań właściwości mechanicznych typowych stali konstrukcyjnych S235JR oraz S355J2+N po ekspozycji pożarowej. Statyczną próbę rozciągania wykonano na wystudzonych próbkach po uprzednim procesie nagrzewania symulującym oddziaływanie pożarowe. Rozważane były różne scenariusze rozwoju pożaru, a także zróżnicowany sposób studzenia próbek. Maksymalna temperatura nagrzewania osiągnięta w badaniach mieściła się w zakresie 400–800°C. Uzyskane wyniki własnych badań zostały porównane z rekomendacjami innych badaczy dostępnymi w literaturze, dotyczącymi stopnia redukcji właściwości mechanicznych takich jak granica plastyczności, granica wytrzymałości, moduł sprężystości liniowej i graniczne wydłużenie całkowite. Przeanalizowane zostały dwa podejścia wyznaczenia stopnia redukcji właściwości po-pożarowych stali. Pierwsze oszacowanie opierało się na minimalnych wartościach danego parametru uzyskanych z badań, a jego rezultatem są opracowane własne krzywe redukcyjne, modyfikujące dotychczasowe zależności opisywane w literaturze. Drugie podejście, bazujące na analizie statystycznej na podstawie PN-EN 1990 pozwoliło wyznaczyć współczynniki redukcyjne oraz współczynniki częściowe, służące do wyznaczenia odpowiednio wartości charakterystycznej i obliczeniowej granicy plastyczności i wytrzymałości na rozciąganie badanych stali w zależności od maksymalnej temperatury nagrzewania. Podsumowanie artykułu stanowi porównanie wartości przyjmowanych do obliczeń przy analizie konstrukcji po pożarze, w oparciu o dwie opracowane metody.

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