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Research paper

Post-fire hardness and impact resistance tests of high-strength grade 8.8 steel bolts

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Abstract: The article presents results of hardness and impact resistance tests of grade M20-8.8 bolts, previously subjected to simulated fire conditions. The tests were aimed at assessing the effect of temperature, fire exposure time, and cooling method on the hardness and impact resistance of bolts subjected to a fire in the context of fastener post-fire suitability for further use. Knowledge of these two parameters may be crucial from the point of view of expert assessment of the safety of structures that survived the fire. This may be of particular importance in the case of structures located in seismic and paraseismic areas, and subject to dynamic loads. Test specimens were received from bolts previously subjected to simulated thermal actions, which were supposed to reflect environmental conditions of a real fire. They were heated at temperatures of 100°C, 150°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C, 800°C, 900°C, and 1000°C for periods of 30', 60′, 120′ and 240′, respectively, and then cooled at various rates, which resulted in the differentiation of the material microstructure. After heating, some of the bolts were cooled naturally, left to cool down freely at ambient temperature, whereas some other were rapidly cooled by immersion in water until they cooled completely, thus simulating the effect of an intensive firefighting operation. The obtained results were elaborated on to assess their usefulness in the analyzes of structures that survived the fire and, due to the nature and extent of damage, are the subject of considerations regarding the possibility of their further use.

Keywords: fire exposure, hardness, heating and cooling process, high-strength steel bolt, impact resistance, residual post-fire properties

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1. Introduction

There is no doubt that knowledge of the post-fire mechanical properties of construction materials is an issue of key importance in the process of expert assessment of the possibility of further safe operation of building structures that have experienced this type of incident and managed to survive it relatively intact. Depending on the construction material, the size of these parameters may depend on numerous factors, which undoubtedly include the temperature reached during a fire, the exposure time to specific thermal conditions, and the method of cooling a heated structure. An expert assessment of fire damage usually involves, as a first step, a thorough inspection of the structure, combined with a detailed survey of permanent deformations. Typically, it is also supplemented with laboratory tests of samples taken from structural members, such as the static tensile test, which is the most popular and most frequently used assessment method. Its main purpose is to evaluate the change in typical mechanical properties caused by environmental impacts experienced as a result of a fire incident. According to experts' opinions [1, 2], this scope of testing can be considered as definitely insufficient for the correct assessment of permanent changes in steel properties, caused by episodes of its heating and cooling in a fire. What is of particular importance for the possibility of further safe operation of a building structure is the determination of the effective post-fire ductility and brittleness of steel. Depending on the temperature reached, the fire scenario and the extinguishing method, there is a high probability of a significant decrease in the ductility of steel, which is accompanied by an increase in its brittleness. This phenomenon is characteristic of all structural steels, but it can be highly intensified – and therefore much more dangerous and less predictable – in the case of bolt steel, previously subjected to heat treatment in the production process. Insofar as properly designed and carried out classic heat treatment is a process aimed at improving the properties of steel, it has a controlled course and its results are predictable [3, 4], the same cannot be said about the conditions that occur during a fire, as it is a typically random process, independent of human will, in most cases without any possibility of control, often occurring abruptly, and having local range. Hence, its effects are unpredictable and usually lead to a state far from user's expectations and will, including partial or complete degradation of the structure, [3, 4]. Experience gained from expert activity shows that a properly designed steel structure, whose components are characterized by yield parameters resulting from ductility and impact resistance, properly adapted to its operating conditions, usually deteriorates progressively in the event of a disaster or failure, first sending the user proper "warning signals" that inform about irregularities and enable evacuation, if needed. A structure in which the effective ductility of steel decreases as a result of exposure to fire actions with simultaneous increase in its brittleness, may be destroyed more abruptly, thus becoming less safe and unpredictable. This is particularly important in the case of structures subjected to dynamic loads or those located in seismic or paraseismic areas.

1.1. Impact resistance

By testing impact resistance, we check how much energy a material can absorb during a sudden impact at a given temperature. By performing an impact resistance test, we also indirectly check resistance of a given material to brittle fracture, which is a key parameter in the case of structures subjected to dynamic loads. A characteristic feature of impact resistance tests, in comparison to static tests is, that they allow easier detection of structural defects in the material and – with adequate testing equipment – more accurate determination of changes in the resistance properties of materials subjected to both controlled and random technological processes. Another important aspect here is in what conditions the structure operates. A drop in the operating temperature of the structure usually results in a decreased impact resistance of steel and, consequently, the risk of turning into brittle scrap. Such a rapid decrease in the impact resistance can happen even within a small temperature range, therefore it is generally crucial to conduct tests in a wider than designed temperature range, adequate to the operating conditions. This is of particular importance in the case of building structures operating at low temperatures (e.g. structures of cold stores or freezers, fruit and vegetable stores, isothermal tanks) or those exposed to variable weather conditions in the open air. If the operating conditions of a given building are characterized by a constant temperature above zero, the structure is not expected to be exposed to variable environmental conditions or its exposure to low temperatures is out of question, then testing in the method corresponding to the conditions of normal use seems to be sufficient. Structural changes occurring in steel as a result of uncontrolled heating and cooling are a fact, but the scope of these changes depends on many factors, including the temperature and pace of heating, time of exposure to elevated temperature, and cooling rate. This has been confirmed in numerous published scientific papers, such as [5–17]. The changes underlying microstructural transformations are particularly noticeable when the temperature during fire exposure exceeds 700–800°C; in this case the dependence on the cooling rate is the most visible. Confirmation of this fact can be found, among other publications, in [18], which describes the tests of steel specimens heated to a temperature of 600–1000°C and then cooled at different rates. The paper was devoted to a microstructural analysis of specimens depending on the cooling rate. In the case of cooling in air, regardless of the level of the maximum soaking temperature, 80% of the ferritic fraction and 20% of the pearlitic fraction were recorded in the microstructure of the samples. In the case of accelerated cooling in water, after exceeding the phase transformation temperature during soaking, the presence of both bainitic and martensitic fractions was recorded, and the percentage content of these fractions was getting higher along with an increase in the temperature at which the cooling process began. The microstructural tests were confirmed by destructive tests, such as the static tensile test and impact resistance test, which showed that the presence of the bainitic and martensitic structure, resulting from accelerated cooling, leads to a significant reduction in the ductility and impact resistance of the steel. Today's assessment of steel resistance to brittle fracture is carried out in the classical Charpy impact test, performed in the most basic range, resulting from standards [19, 20]. The assessment of steel resistance to fracture based on the abovementioned test is supplemented by the analysis of the fractured surface of the specimen, obtained from the impact resistance test, which can be performed on specimens with rectangular cross-sections. The standard specifies three types of fracture modes occurring in the impact test. These are, respectively, plastic fracture, brittle fracture and – the most typical – mixed mode fracture, also called plastic-brittle or ductile fracture, i.e. containing both plastic and brittle fractured surfaces. The classic impact test remains the most popular method of assessing the fracture resistance of a material, cf. inter alia [20, 21, 23]. Due to its simplicity, it does not allow for detailed identification of respective phases of the fracture process, it only illustrates the amount of total energy necessary to break the sample, [24, 25]. Nevertheless, it can be used, for instance, to see whether the measured post-fire fracture energy of steel is not lower than the minimum energy required for a specific steel grade to prevent spontaneous cracking of the material. It has been experimentally demonstrated that in the case of steel specimens for which the observed fracture contains at least 70–90% of ductile fracture, the development of such cracks can stop naturally, without causing any catastrophic effects, [26]. Therefore, the assessment of the nature of the crack, made on the basis of identification of the relative share of plastic fracture and brittle fracture, can be very helpful in drawing conclusions about the possible further use of the tested structural member after a fire. Undoubtedly, more precise information on the course of the cracking process can only be obtained in the instrumented impact test, carried out on the basis of the standard [27]. Examples of conclusions drawn in regard to the possibility of further operation of structural members made of SN490C steel after a fire, based on the classic impact testing, can be found in [18]. In [28], the susceptibility of welded steel connections to cracking at elevated, as well as the ambient temperature after heating and cooling process was assessed using the classic Charpy impact test, taking into account both various methods of cooling and differentiated test conditions, corresponding to real conditions of the structure's operation. A similar analysis of the effect of the cooling method and the maximum heating temperature on the value of the fracture energy was carried out in [29]. Obtained results were confirmed in hardness tests using the Vickers method and in microstructure tests. The Charpy impact test was also used in [30] to assess the fracture resistance of various grades of 500 MPa reinforcing steel after simulated fire exposure and cooling in air. In [31], the classical Charpy impact test was used to assess the quality of steel in bridge structures that survived a fire. The impact resistance test conducted at ambient temperature showed a considerable decrease in fracture energy in the case of specimens subjected to rapid water cooling. As reported by the authors of [29], similar conclusions were obtained in studies on Japanese JIS SN400B, SA440B and SN490B steels, described in [32, 33]. In [34–38], it was shown that fracture energy depends on both the maximum heating temperature and the cooling rate.

1.2. Hardness

Hardness is one of material parameters that is equally important from a design and technological point of view as its ultimate tensile strength, percentage elongation, percentage reduction of area, impact resistance, etc. Due to the relationship between certain material properties, a hardness test, as relatively easy to perform, not only in laboratory conditions, can also be used to determine an approximate value of tensile strength. The assessment of the tensile strength of steel by measuring its hardness is used when there is no possibility to make specimens and conduct relevant tests in a laboratory, since it would involve, for example, unacceptable destruction of the structure. The popularity and usefulness of hardness tests, just as their quite universal nature, also results from the possibility of using them in expert assessment of a structure that has survived a fire. This is due not only to the easiness of establishing a relationship between the results of measurements of hardness and other mechanical properties, but above all, by the speed, comfort and acceptable accuracy of measurements, the possibility to take them in conditions in which tests of other mechanical properties could not be carried out, minor damage to tested specimens or products, as well as the simplicity and mobility of measuring instruments. Hardness tests can be conducted using one of the methods described in detail in standards [39–41]. In the case of hardness tests performed on structural members that have been exposed to a fire, it is nevertheless necessary to remember to properly prepare the surface of the members used for testing by adequate cleansing, as it may contain superficial layer changes that could affect the quality of obtained results, the range of which depends on the temperature reached in a fire [2].

2. Experimental study

2.1. Test specimens and methods

To prepare specimens for hardness and impact resistance tests, M20/200 grade 8.8 construction bolts were used, made of chromium alloy steel with the addition of boron, symbol 32CrB3, the chemical composition of which is given in Table 1 according to the manufacturer's certificate, which were previously used for shear resistance tests, described in more detail in [6].

Table 1. Chemical composition of the 32CrB3 bolt steel

Steel designation	**Chemical composition [%]**										
32CrB3	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Mo	Sn
	0.31	0.84	0.13	0.012	0.013	0.74	0.08	0.15	0.025	0.018	0.010
	V	Ti	B	Zn	Ce	N	Al_m	Ca	As	Nb	Sb
	0.004	0.047	0.002	0.028	0.62	0.0114	0.022	0.0023	0.007	0.001	0.002

The bolts were made of smooth wire rod in the cold forging process and then, in order to obtain the expected mechanical properties corresponding to strength of grade 8.8, they were heat-treated by quenching in oil at a temperature of approx. 850–860°C and tempering at a temperature of approx. 550°C.

Before making the specimens, the unloaded bolts in "as-delivered" condition were subjected to heat treatment corresponding to the selected environmental impacts of a simulated fire, by soaking them in batches in an electric furnace respective temperatures of: 100°C, 150°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C, 800°C, 900°C, and 1000°C, for 30′, 60′, 120′ and 240′, respectively. The bolts were placed into the furnace chamber previously heated to the desired temperature, kept in these conditions for 5–10 minutes, so that they would reach the required temperature, after which the soaking time measurement was started. The temperature of the furnace chamber was controlled by means of 4 thermocouples, evenly distributed within the furnace chamber. Following such thermal exposure, some of the bolts were removed from the furnace and left to naturally cool at ambient temperature (air-cooling/specimen symbol:

AC). This was supposed to correspond to the situation of spontaneous, natural termination of fire, resulting either from a lack of oxygen or a shortage of flammable substances. The second batch of bolts was shock-cooled by immersion in water (water-cooling/specimen symbol: WC), which was intended to simulate the conditions of an intensive firefighting operation, carried out by fire brigades. In each series, for statistical reasons, 3 specimens were tested. This number also includes specimens in their initial state, treated as reference. Apart from the reference specimens in the initial state (IS-20), the remaining specimens were marked according to the X/Y/Z scheme, where X denotes the cooling method, Y – the soaking temperature, and Z – the time of soaking in set thermal conditions.

Non-standard specimens were used in the impact resistance tests, whose shape did not correspond to the guidelines provided for in the standards [19, 20], which – from a practical point of view – was intended to confirm the possibility of obtaining reliable experimental results without the need for prior excessive mechanical processing of the specimens. At the same time, this approach was supposed to demonstrate the possibility of conducting tests in on-site conditions, while minimizing additional costs. The geometry of the specimens is shown in Fig. 1. The distance between the Charpy pendulum hammer supports was adjusted to the width of the pendulum knife as well as the diameter of the tested bolts, and was established as 58 mm. The same specimens were used for hardness tests, which were carried out using the Rockwell method, in accordance with [39], before impact testing. The Rockwell method was chosen because it can be used on materials of varying hardness or products with curved surfaces, measurements are relatively fast and it is easy to read the final result.

(a) (b) (c)

Fig. 1. Specimens for impact resistance tests: (a), (b) specimen geometry, (c) method of supporting the specimen and the adopted distance between the Charpy pendulum hammer supports

Specimens that can be used in this method do not require any particularly exact preparations and, in the case of a testing device with analogue reading, correctness of the result is not burdened with the human error or imperfections of optical systems, as in the case of Vickers or Brinell hardness testers. Owing to the size of the device, it is also easy to transport it and use for field testing. Although the Rockwell method is considered to be the least accurate, it seems precise enough for industrial purposes, which is confirmed by its common use in the product quality control procedure.

2.2. Test setup and procedures

Both hardness tests and impact resistance tests were carried out at ambient (room) temperature, based on the assumption that most structures of enclosed buildings are operated in conditions of regulated temperature during their technical life, which is typical for rooms intended for permanent or temporary stay of people.

Hardness measurements were taken on the cylindrical side surfaces of the specimens using a hardness tester with an analogue reader, on a pointer clock, by the American company Wilson Mechanical Instrument Co. Inc., with the use of a factory table for cylindrical specimens, which was part of the device. At least 6 measurements were taken on each sample, taking readings on the A, B or C scale, depending on the hardness of the material. Extreme and outlier results were rejected, whereas the remaining ones were averaged. Corrections were introduced to the values so obtained, to take into account the fact of performing the hardness measurement on a cylindrical surface, in accordance with Annex C to the standard [39]. The test specimens at the points of measurement and support on the table were cleaned of oxides and foreign bodies, and then degreased with petroleum ether. The obtained results, in order to unify them and bring them to one common scale, after averaging, were converted [42] to Brinell hardness scale, which is directly applicable to the approximate estimation of the tensile strength of steel.

The impact resistance test of the specimens was performed using the Charpy method, by means of a pendulum hammer by a Swiss company Alfred J. Amsler & Co., with an initial range/energy of 300 J and the smallest scale interval of the measuring device of 5 J. Due to the relatively large width of a single division on the measuring scale, readings were taken with greater precision. The notch in the sample was initially cut to a depth of half its thickness/half the diameter of the bolt, according to Fig. 1, and then, at the stage of preliminary tests, the final depth of the notch cut was verified so that the specimens would be completely or partially broken as a result of the pendulum impact on each of the specimen series. Such an approach meant that due to the uneven depth of the notch, a direct comparison of the measured values of the absorbed fracture energy K, measured in [J], would be unreliable. Therefore, the results of the experiment were presented in the form of impact resistance KC, measured in [J/cm^2], defined as the ratio of the energy used to break the specimen to its cross-sectional area at the point of weakening by the notch. The shape of the notch bottom did not correspond to the standard geometry of the "U" or "V" type notch, because it was cut with a classic metal cutting disc. The purpose of this approach was to demonstrate, among other things, the usefulness of the results obtained from tests carried out on specimens prepared with the use of widely available tools, without the need to employ specialist workshops. In order to ensure that the specimen would be properly positioned on the supports, a template was used to position it. After the test, due to the unconventional shape of the specimens, only the impact resistance value and the qualitative failure of the specimen were subject to comparative assessment. Quantitative measurement of specimen lateral expansion LE, in accordance with the principles adopted in [19], was impossible.

2.3. Experimental results and discussion

The obtained results of the hardness and impact resistance measurements were compared in common diagrams with the values of post-fire tensile strength obtained in the static tensile test of bolts [6], Fig. 2. In the case of the specimens cooled in air, a slight decrease in post-fire tensile strength is noticeable for the members soaked at 300°C, which does not reveal after soaking at 400°C. At the same time, we observe that it is accompanied by a slight increase in the hardness of the material, in relation to the values measured on the specimens for which the soaking temperature was 200°C. In the case of the specimens soaked at 400°C, the effect is the opposite – a certain increase in post-fire tensile strength is accompanied by a noticeable decrease in the hardness of the material. This is the effect of the "blue brittleness" phenomenon, which is a strain ageing mechanism that occurs in the material, caused by the precipitation of tertiary cementite or carbonitrides of alloying elements at the grain boundaries of the structure [2]. In the case of structural steels, for which this phenomenon has been better analyzed, it is usually accompanied by a deterioration of plastic properties and an increase in the brittleness of the steel. For specimens soaked for 30′ and 60′ at 500°C, we observe a repeated increase in hardness, which is not so clearly visible in the case of a longer exposure time to the set temperature. After exceeding the tempering temperature in the production process (i.e. approx. 550°C), both the post-fire tensile strength and hardness values gradually decrease.

In the case of specimens cooled in water in an accelerated manner, the "blue brittleness" effect is not so evident. After exceeding the austenitization temperature Ac_1, both the post-fire tensile strength and the hardness of the material begin to increase quite rapidly and for soaking times of 30′ and 60′, they reach maximum values for specimens soaked at 900°C. A longer time and a higher temperature of soaking lead to a decrease in both, the residual tensile strength and hardness of the bolt steel. This is the effect of overheating the steel, excessive growth of austenite grains, and as a result – the coarse-grained structure of the resulting martensite and significant structural stresses in the material.

When analyzing the results of the material hardness measurements presented in Fig. 2, a conclusion can be drawn that after fire exposure, during which the temperature did not exceed 500°C, (disregarding small localized deviations resulting from such issues as, say, the conversion of measurements), the impact resistance of steel, regardless of the soaking time and the adopted cooling rate, remains at a relatively uniform level, close to the reference value. Once the bolt tempering temperature in the production process is exceeded, the impact resistance starts to increase, which indicates rising plasticity/ductility of the material.

The highest impact resistance is characteristic of the specimens soaked at temperatures lower than Ac_1, i.e. just before the initiation of the phase transformation, and this is a regularity independent of both the soaking time and the adopted cooling method. Only in the case of the specimens soaked for 30′ and left to cool down in air, the highest impact resistance was recorded for members soaked at 800°C. In the case of the specimens soaked at higher temperatures, the impact resistance decreases, however for the specimens cooled naturally, it returns to the values measured for temperatures in the range of 20–500°C, while in the case of the specimens rapidly cooled in water, the impact resistance decrease is much more significant, to a level of approx. 41–46% of the reference value. The nature of the changes is also visible in the specimen fractures, shown in Figs. 4–5. Due to the volume limitations, only the fractures of the specimens corresponding to the soaking temperatures before, during and after the phase transformation of steel are shown, as well as the fracture of the specimen in the reference state, Fig. 3.

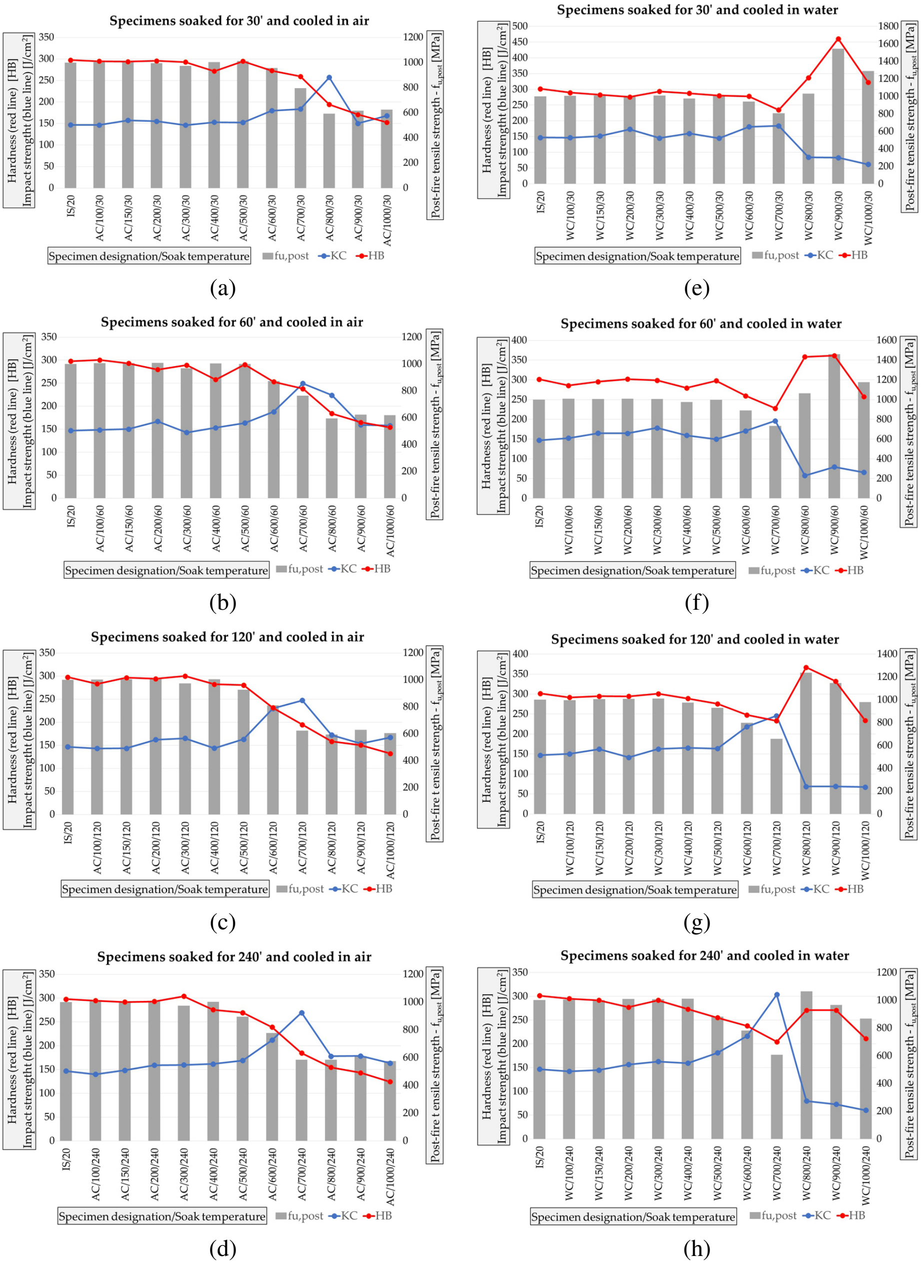
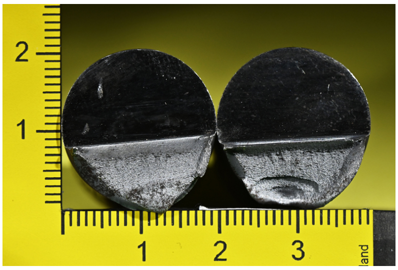


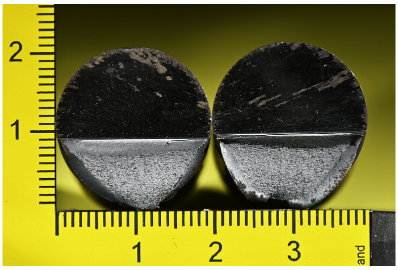
Fig. 2. Tensile test diagrams for varied soaking time, cooling methods, and temperature conditions: (a) 30′, (b) 60′, (c) 120′, (d) 240′ of soaking time, specimens cooled in air; (e) 30′, (f) 60′, (g) 120′, (h) 240′ of soaking time, specimens cooled in water



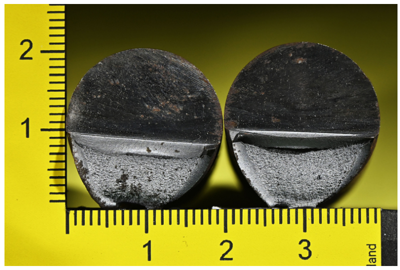
(a)

(b)

Fig. 3. Sample fracture of IS/20 specimens (initial state/as delivered), after impact testing:
(a) IS/20, (b) IS/20 – details of fracture

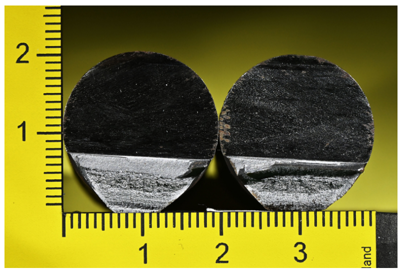


(a)

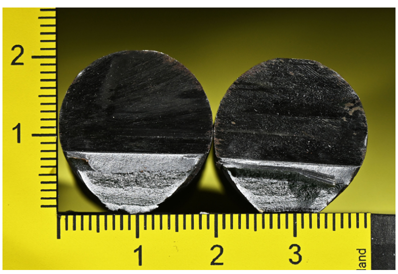


(b)

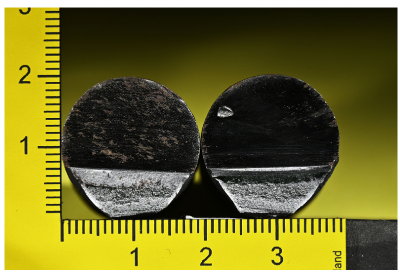
(c)



(d)



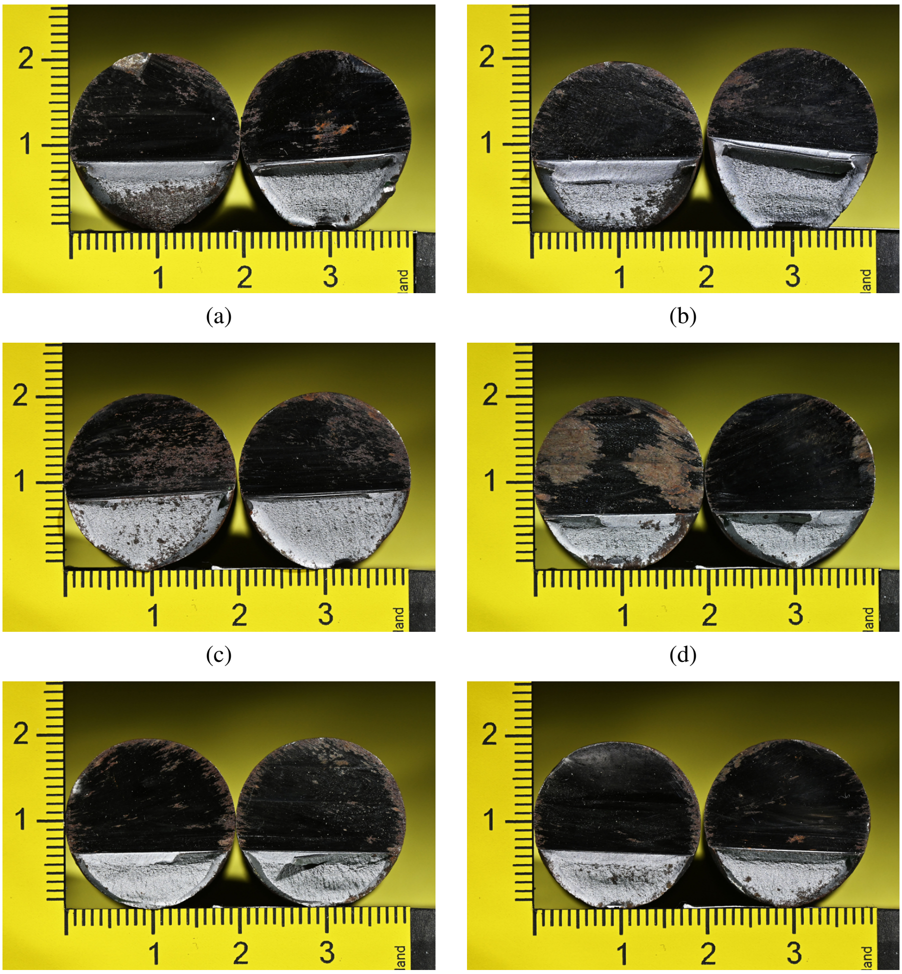
(e)



(f)

Fig. 4. Sample fractures of AC specimens (cooled in air), after impact testing:
(a) AC/600/60, (b) AC/600/240, (c) AC/800/60, (d) AC/800/240, (e) AC/1000/60, (f) AC/1000/240

Photos of the specimens show typical mixed mode fractures of a specimen broken in an impact test, where all areas of respective phases of the cracking process and their mutual dimensional relations can be observed. In the upper part of the fracture, right under the notch, the area of crack initiation and its stable growth is visible. On the sides, along the specimen outline, so-called shear lips can be noticed, responsible for the ductile fracture. In these areas, the number of degrees of freedom of deformation is greater than in the central part of the fracture. Along with an increase in the size of this area, the failure of the specimen is more ductile and the measured absorbed fracture energy gets higher. The part corresponding to



(a) (b) (c) (d) (e) (f)

Fig. 5. Sample fractures of WC specimens (cooled in water), after impact testing:
(a) WC/600/60, (b) WC/600/240, (c) WC/800/60, (d) WC/800/240, (e) WC/1000/60, (f) WC/1000/240

unstable brittle fracture is visible in the central part of the fracture, in the form of the cleavage fracture area. In the bottom, lowest part of the fracture, near the pendulum impact point, the final fracture area can be seen.

In specimens with a more plastic fracture character, the final fracture area is more pronounced, which is clearly visible in Fig. 3(a). In Fig. 3(b) macroscopic differences in the appearance of respective fracture areas can be observed.

3. Conclusions

The article presents and discusses the results of hardness and impact testing measurements performed on the specimens made of grade 8.8 steel bolts, quenched and tempered in a production process, previously subjected to the environmental conditions of a simulated fire. The research was aimed at determining the effect of the soaking temperature, exposure time in the given thermal conditions, and the cooling method on selected mechanical properties of bolts after the fire, relevant from the point of view of assessing the possibility of their re-use, if at all, in modernized load-bearing structures.

Based on the results obtained and the observations made, the following conclusions can be drawn:

– it should be noted that the results of hardness and residual tensile strength measurements reflect a similar trend, which confirms both the close correlation between these two values and the qualitative correctness of the obtained results. In practice, this also confirms the possibility of using hardness measurements to estimate the tensile strength of steel after a fire episode,
– due to the shape of the specimens used in the impact resistance tests, it is not possible to determine the value of *LE* – lateral extension, interpreted as a measure of the material's ability to inhibit crack propagation, according to the standard [19] assessment of the material's plasticity. Based on the traditional, although rather subjective, visual assessment (despite its limited precision), it can be concluded that in the case of more plastic fractures, the shear lips are noticeably wider and the fracture area is more pronounced, while the central zone – reflecting the material's susceptibility to brittle fracture, is much smaller,
– although the results of the completed tests, at least in the case of impact testing, should be considered more in qualitative than strictly quantitative terms, they clearly show changes in the mechanical properties of bolt steel that are crucial to the structural safety, depending on the fire scenario. Still, one should bear in mind that they are burdened with the error caused by lack of model similarity, due to different depths of notch cuts,
– the obtained results show that in the case of bolts cooling down naturally after a fire, changes in impact resistance, assessed through the prism of safety and integrity of the structure, seem harmless and should not cause the risk of its sudden, uncontrolled failure. On the other hand, rapid cooling of the structure, which may happen during fire extinguishing operations, in the case of bolts heated above the Ac_1 – initiation temperature of the phase transformation, results in a drastic decrease in impact resistance (increased

brittleness) of the steel. This may turn out to be a potentially dangerous phenomenon and perilous in its consequences, especially for dynamically loaded structures, or those situated in seismic or paraseismic areas,

- the presented hardness test results confirm that the use of the Rockwell method of measurement, although generally considered as the least precise, followed by conversion of these results to the Brinell hardness scale, as well as the use of non-standard specimens in impact testing, does not change the nature of the results and their correctness in qualitative terms. They confirm the usefulness of relatively simple testing methods in expert assessments of the performance properties of bolts and other steel members, which are important for the safety of the structure, in the context of the possibility of their further use in buildings modernized after a fire,
- it should be emphasized that the presented results refer only to tests carried out at room temperature. One should bear in mind that tests conducted at lower temperatures could provide additional information on changes in material properties that were not observed herein and result in more precise conclusions. This remark applies especially to the results from the impact test,
- the obtained results confirm the observations reported in the cited bibliographic sources in relation to other types and grades of steel.

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Pomiary twardości i udarności śrub o podwyższonej wytrzymałości klasy 8.8, po symulowanej ekspozycji pożarowej

Słowa kluczowe: ekspozycja pożarowa, proces nagrzewania i chłodzenia, rezydualne po-pożarowe właściwości mechaniczne, śruby o podwyższonej wytrzymałości, twardość, udarność

Streszczenie:

W artykule zaprezentowano wyniki pomiarów twardości oraz udarności śrub jakościowych M20-8.8, wykonanych ze stali stopowej 32CrB3, poddanych wcześniej symulowanym oddziaływaniom pożarowym. Celem badań była ocena wpływu temperatury, czasu ekspozycji pożarowej i metody chłodzenia na twardość i udarność śrub po ekspozycji pożarowej, w kontekście przydatności łączników do ich dalszego wykorzystania, po pożarze. Znajomość tych dwóch parametrów – poza wynikami uzyskiwanymi tradycyjnie z klasycznej statycznej próby rozciągania – może być istotna z punktu widzenia eksperckiej oceny bezpieczeństwa konstrukcji, które przetrwały pożar. W szczególności może mieć znaczenie w przypadku konstrukcji zlokalizowanych na terenach sejsmicznych i parasejsmicznych, oraz obciążonych w sposób dynamiczny. Próbki do badań pobrano ze śrub poddanych uprzednio symulowanym wpływom termicznym, mającym odzwierciedlać warunki środowiskowe realnego pożaru, wygrzewanych w temperaturze 100°C, 150°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C, 800°C, 900°C i 1000°C przez okres odpowiednio 30′, 60′, 120′ i 240′, a następnie studzonych ze zróżnicowaną prędkością, co finalnie spowodowało zróżnicowanie mikrostruktury materiału. Po wygrzaniu, część śrub chłodzono w sposób naturalny, pozwalając im ostygnąć swobodnie na powietrzu, drugą zaś część studzono w sposób gwałtowny, przez zanurzenie w wodzie aż do całkowitego wystudzenia, symulując tym samym efekt akcji ratunkowo-gaśniczej. W każdej z serii przebadano po 3 próbki, celem weryfikacji poprawności i powtarzalności uzyskanych wyników. Omówiono uzyskane wyniki oceniając ich przydatność w analizach konstrukcji, które przetrwały pożar i z uwagi na charakter oraz wielkość zniszczeń rozważa się możliwość ich dalszej eksploatacji.

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