Mechanical Behavior Analysis of Stainless Steels Subjected to Uniaxial Stress Tests

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Abstract. The fundamental problem considered in this paper is the choice of materials, in this case stainless steels, for a particular industrial purpose. The choice of the appropriate material should be made based on the material behavior database established by experimental investigations. The mechanical behavior and mechanical properties of several stainless steels, such as ferritic, martensitic and austenitic stainless steels are investigated and analyzed in this research. Mechanical properties at room and high temperatures, creep behavior at different high temperatures and different stress levels as well as Charpy fracture impact energy were considered for several of the steels mentioned. Fracture toughness, based on the Charpy impact energy is calculated using known analytical procedure. In this sense, material properties are determined based on displayed engineering stress-strain diagrams while material creep behavior is displayed in the form of creep curves. Some of numerical values regarding the ultimate tensile strength, measured at room temperature, are given using the following order and in the following form: \[ \sigma_{\text{m,Mat,NR}}^{20^\circ \text{C}} \]. In this sense, the stress levels of the are:

\[925_{1.4122}, 782_{1.4034}, 726_{1.4305}, 686_{1.4841}, 585_{1.4762}, 607_{1.4541} \, 20^\circ \text{C}.\]

1. Introduction

Modern design of engineering structures or their elements is based on proper selection of materials and numerical control of mechanical behavior. In any case, designing of structures that must be safe, reliable and economical, requires efficient selection and use of material but also assurance that failure during structure life will not occur [1]. Over the long term, the finite element method has become a very attractive technique in the computer processing of complex engineering solutions [2]. In accordance with the purpose of the structure, some structure is subjected to high stress, another one to high temperature or to repeated load, etc. However, design of the considered structure need to be made from the best material that can meet all of requested requirements, and usually, under assumption that material is free of any failure and that no failure during structure life will occur. In spite of this desire and all the best design pleasures, various failures are possible during the operation of the structure under the prescribed environmental conditions and loads. Usually, in engineering practice, two main groups of failures can be spotted and those are preexisting failures in material and failures that can occur during structure lifetime (from design through maintenance and inspection to the regular workload). Commonly observed mechanical failures can be listed as excess deformation, corrosion, impact, creep, fracture, fatigue, wear, etc. [3]. In this investigation, apart the mechanical properties as the most important task at material selection, some of mentioned failures, such as yielding, creep or, for example, fracture impact energy, were explored. It is known that, in general, creep can occur in
metals at temperature of 370°C, or it can be said that in engineering practice creep is appreciable above $0.4T_m$, where $T_m$ is melting point measured in Kelvin [4]. In this sense the investigation of creep behavior of considered materials is very important. From the other hand, investigation regarding the energy of impact fracture is also of great importance, since based on it, someone can assess the fracture toughness using, for example known analytical formula. The main intention in these investigations was to provide information in one place of utmost importance for the selection of materials and the possibility of their comparison. With regard to the materials being researched, some of the results by individual research items can be found in the available literature, such as the following papers. In Refs. [5-6], some investigation results regarding the material properties and mechanical behavior of material 1.4762 are presented, in Refs. [7-8] also some results regarding mechanical properties and corrosion behavior of 1.4122 material are presented. Further, in Refs. [9-10], experimental results regarding material properties of material 1.4841 are given. Similar, in Refs. [11-12] experimental results regarding the mechanical behavior of material 1.4541 are presented. In addition, for other here investigated materials, also some data regarding their mechanical behavior can be found in the published papers. Experimental tests were carried out according to the standards given in Ref. [13].

1.1 The significance of this research

This research has a wide range of meanings. The study of mechanical properties indicates the level of stress and deformation that the studied materials can withstand at different temperatures. Furthermore, the creep resistance indicates at which temperatures and load levels the materials can be used for a certain period of time, and finally what the impact energy of the fracture of individual materials is. Taken together, the result indicates how well these materials are suitable for particular applications.

2. Materials, equipment and standards

Materials whose mechanical behaviors are being investigated are (mat. numbers): 1.4122, 1.4034, 1.4305, 1.4841, 1.4762 and 1.4541. Their chemical compositions regarding to only some of constituents are presented in table 1, while in table 2 are given data regarding the type of the material and application possibilities.

| Material / round bar (mm) | Chemical composition (some elements only), mass % |
|--------------------------|---------------------------------------------------|
| 1.4122 (X39CrMo17-1)/18 | C 0.39  Cr 16.4  Si 0.45  Ni 0.35  Mn 0.56  Mo 0.81 |
| 1.4034 (X46Cr13)/16     | C 0.44  Cr 13   Si 0.37  Ni -      Mn 0.38  Mo -      |
| 1.4305 (X10CrNiSi18-9)/18| C 0.047 Cr 17.3 Si 0.58  Ni 8   Mn 2   Mo -      |
| 1.4841 (X15CrNiSi25-20)/16| C 0.027 Cr 24   Si 2.7   Ni 20.2 Mn 1.6  Mo 0.2  |
| 1.4762 (X10CrAlSi25)/18 | C 0.102 Cr 23   Si 1.2   Ni 0.68  Mn 0.52  Mo 0.12 |
| 1.4541 (X6CrNiTi18-10/18| C 0.017 Cr 17   Si 0.44  Ni 9.3   Mn 1.44  Mo 0.24 |
Table 2. Tested materials: Type and application possibility (A-austenitic; F-ferritic; M-martensitic)

| Material      | Type | As-received | Application                                                                 |
|---------------|------|-------------|-----------------------------------------------------------------------------|
| 1.4122 (X39CrMo17-1) | M    | -           | Mechanical engineering (compressor and pumping parts, shafts, valves, polymer industry ) |
| 1.4034 (X46Cr13)  | M    | annealed+cold drawn | Mechanical-civil-industrial engineering (shafts, pumps, gears, etc)         |
| 1.4305 (X10CrNiSi18-9) | A    | cold drawn  | Mechanical engineering (heavily machined parts, shafts, gears valve parts, screws, bolts, food ind.) |
| 1.4841 (X15CrNiSi25-20) | M    | annealed+cold drawn | Aerospace – shipbuilding - military industry, nuclear power industry. Thermal treatment plants. |
| 1.4762 (X10CrAlSi25) | F    | annealed    | Oil-chemical-petroleum-ceramics-cement industry, furnace, steam boilers technology. |
| 1.4541 (X6CrNiTi18-10) | A    | annealed    | Automotive-chemical-building-construction-aerospace industry.               |

3. Test results and analysis

3.1 Mechanical behavior of materials at different temperatures

Engineering stress-strain diagrams for tested materials are shown in figure 1. Based on these figures it is possible to make some comparison regarding the ultimate tensile strength. See also data in table 3.

![Figure 1. Engineering stress-strain diagrams of tested material at room temperature and that of 500°C](image1)

3.2. Short-time creep tests

Short-time creep tests for considered materials are shown in figure 2 regarding the temperatures of 500°C and 600°C. At temperature of 500°C all of tested materials were subjected to stress level of 0.5 yield strength at considered temperature. Although stress level is not the same for all of materials, it is visible that materials 1.4841, 1.4305, 1.4541 may be treated as creep resistant at these conditions, while other considered materials may not be. For the same materials tested at temperature of 600°C and stress levels shown in figure 2, it can also be said that they are creep resistant.
Figure 2. Creep curves of tested materials at temperatures of 500°C and 600°C

The effect of temperature on considered materials may be summarized as it is shown in table 3.

Table 3. Effect of temperature on mechanical behavior of considered materials

| Material | Type | Ultim. tensile strength, $\sigma_m$ MPa | $\sigma_{m,500}/\sigma_{m,20}$ | Creep resistant 500°C, 600°C |
|----------|------|----------------------------------------|-------------------------------|-----------------------------|
|          |      | 20°C | 500°C | $\xi$ | +/− |
| 1.4122   | M    | 925  | 453   | 0.49 | −   |
| 1.4034   | M    | 782  | 352   | 0.48 | −   |
| 1.4305   | A    | 726  | 445   | 0.61 | +   |
| 1.4841   | A    | 686  | 508   | 0.74 | +   |
| 1.4762   | F    | 585  | 270   | 0.46 | −   |
| 1.4541   | A    | 607  | 372   | 0.61 | +   |

3.3 Charpy V-notch impact fracture energy
In figure 3 curves representing Charpy impact energy are shown. Using well known Roberts-Newton formula, fracture toughness can be calculated. The result obtained is independent of temperature.
Figure 3. Charpy V-notch impact fracture energy of tested materials.

In accordance with the results of impact fracture energy shown in figure 3, it is visible that the highest value of it occurs at the steels 1.4841 and 1.4541.

4. Conclusion

In this investigation very important and useful experimental data regarding mechanical properties, creep behavior as well as Charpy impact fracture energy were obtained. Based on these results it is visible that the highest ultimate tensile strength at room temperature possesses steel 1.4122, while at temperature of 500°C, the steel 1.4841. Furthermore, the considered steels 1.4305, 1.4841 and 1.4541 can be treated as creep resistant at the temperatures of 500°C and 600°C and for the applied stress levels, while this does not apply to other materials tested. The relatively smallest influence of temperature is evident in the mechanical behavior of the materials 1.4305, 1.4841 and 1.4541.

5. References

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