

APPLICATION OF INSTRUMENTED CHARPY METHOD IN CHARACTERISATION OF MATERIALS

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ABSTRACT

Testing of absorbed impact energy according to the Charpy method is carried out to determine the behaviour of a material under the impact load. Instrumented Charpy method allows getting the force-displacement curve through the entire test, That curve can be related to force-displacement curve which is obtained by the static tensile test. The purpose of this study was to compare the results of forces obtained by the static tensile test with the forces obtained by the instrumented Charpy method. Experimental part of the work contains testing of the mechanical properties of S275J0 steel by the static tensile test and Impact test on instrumented Charpy pendulum.

KEY WORDS

impact test, instrumented Charpy pendulum impact test, tensile test

CLASSIFICATION

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INTRODUCTION

For most mechanically loaded constructions and parts it is very important to ensure the combination of sufficient strength and toughness. The practice shows that a large number of fractures is not the result of previous plastic deformation, but the consequence of stress which is lower than the yield point. Thus, the concept of toughness is closely linked with the notion of fracture. So we identify brittle and ductile fracture [1].

Material toughness is a property that show the ability to absorb mechanical energy, caused by external, mainly impact energy, through the plastic deformation of materials. The amount of energy consumed for plastic deformation and fracture represents a measure of toughness [2].

Impact test determines the behavior of metallic and polymeric materials in terms of impact loads. Impact test tells us about the energy spented for breaking the specimen whit specific shape and dimensions [1]. Places of stress concentration, such as cracks and notches, are the places where the fatigue, which ends with fracture, begins. It is known that the material fracture in the presence of notch is influenced by the fracture toughness of the material. Therefore, the tests are conducted on specimens with the notch and in this way the multiaxial stress is achived at the root of the notch. Many methods to measure the “strength of the notch” of materials had been developed and standardized. The test is usually carried out at room temperature or at reduced temperatures. Triaxial stress state, the high rate of stress and low temperatures contribute to brittle fracture of materials. Therefore, in order to simulate the heaviest load conditions, almost all tests include the notch which gets broken at various temperatures. The value absorbet impact energy indicates whether the material will break ductile or brittle under the impact stress. Absorbed impact energy is a comparative size and can not be used in calculations when sizing the structural components [3].

TESTING OF ABSORBED IMPACT ENERGY BY THE INSTRUMENTED CHARPY METHOD

Impact test according the Charpy is carried out to determine the behavior of materials under impact stress. The amount of the absorbed impact energy indicates the “toughness” or “fragility” of material. Charpy impact test is carried out according to the standard EN ISO 148-1 [4]. The energy needed for the fracture of the sample, whose dimensions are defined by the standard, is called absorbed impact energy and it is determined by the following formula [2]:

$$KU(V) = G (h_1 - h_2) \quad (1)$$

where the $KU(V)$ is absorbed energy (specimens with U or V notch); G is the weight of hammer; h_1 the initial height of hammer and h_2 the final height of a hammer. Figure 1 shows the schematic view of the test.

It should be noted that the usual Charpy method gives only information with comparative character. The conventional impact test method (without instrumentation) measures the energy required to fracture the specimen under impact loading. For a more complete understanding of the formation and expansion of cracks in the test sample due to impact stress instrumented Charpy method has been developed. Instrumented testing on samples with intentionally made cracks had opened the way for the analysis of fracture mechanics parameters important in the creation and growth of cracks at high loads. The test is carried out according to DIN EN ISO 14556 [6]. The test sample is a Charpy V notch and it is in compliance with EN ISO 148-1.

Instrumented Charpy impact test does not only measures the total energy required to fracture the test specimen, but also the energy at the start of the crack in the notch, energy at maximum

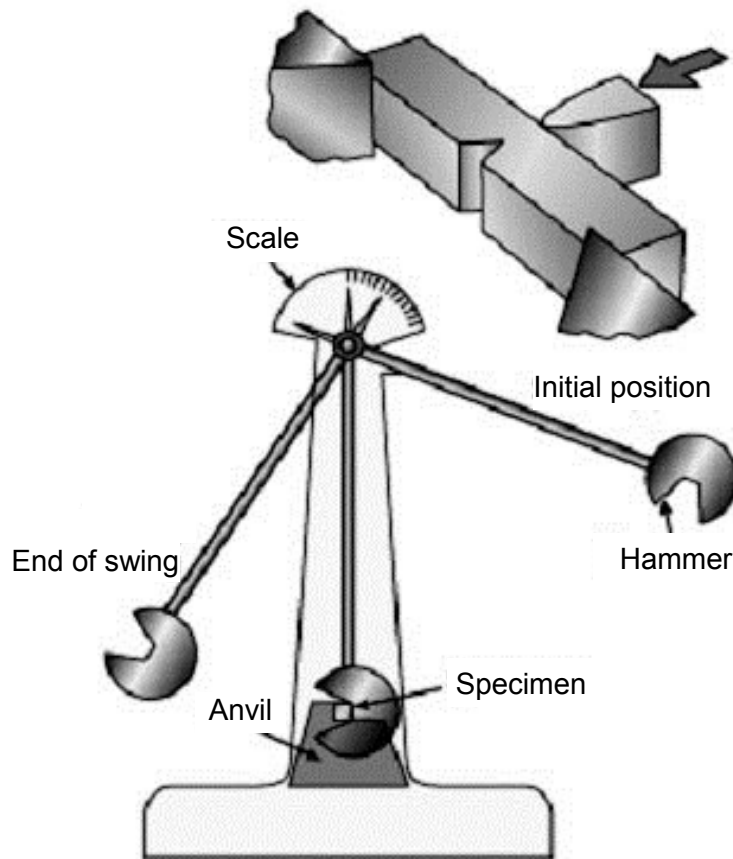


Figure 1. Impact testing according the Charpy method [5].

force and energy at the end of unstable fracture. The method requires the use of hammers, which have built-in strain gage to obtain a load curve throughout the entire test procedure. This provides information about the force, displacement, time, and energies that can correlate with mechanical properties such as toughness, fracture toughness KIC, resistance to the fracture, etc. [7].

The advantage of instrumented method is a record in the form of load curves as a function of time by which the absorbed energy during the test can be measured. The method with data on absorbed energy during the test also includes the value of a force versus time. These parameters provide informations about the mechanisms of cracks. Measurement of the force is usually achieved by the use of two active electric resistance strain gauge tensometers at the standard fixed blade to form a force converter. Design of the blade and associated curves are given in Figure 2.

The system for force measurement (instrumented knife, an amplifier, a recording system) must have a response of at least 100 kHz what corresponds to the rise time, no higher than 3.5 ms. Dynamic estimate of the measurement of force can be simplified by measuring the initial value of the first peak. Experimentally, the dynamics of the measuring chain can be considered satisfactory if the steel test specimen with a V notch shows an initial peak higher than 8 kN when the impact velocity is between 5 m/s and 5,5 m/s. This is true if the centers of the active measuring devices are located between 11 mm and 15 mm from the contact point of the hammer. The instrumentation of the blade must be set up so it can produce an appropriate range of force. Instrumented blade must be designed to minimize the vulnerability to asymmetric loads. Experience tells that with V notch samples, nominal impact force appears between 10 kN and 40 kN for all types of steel [6].

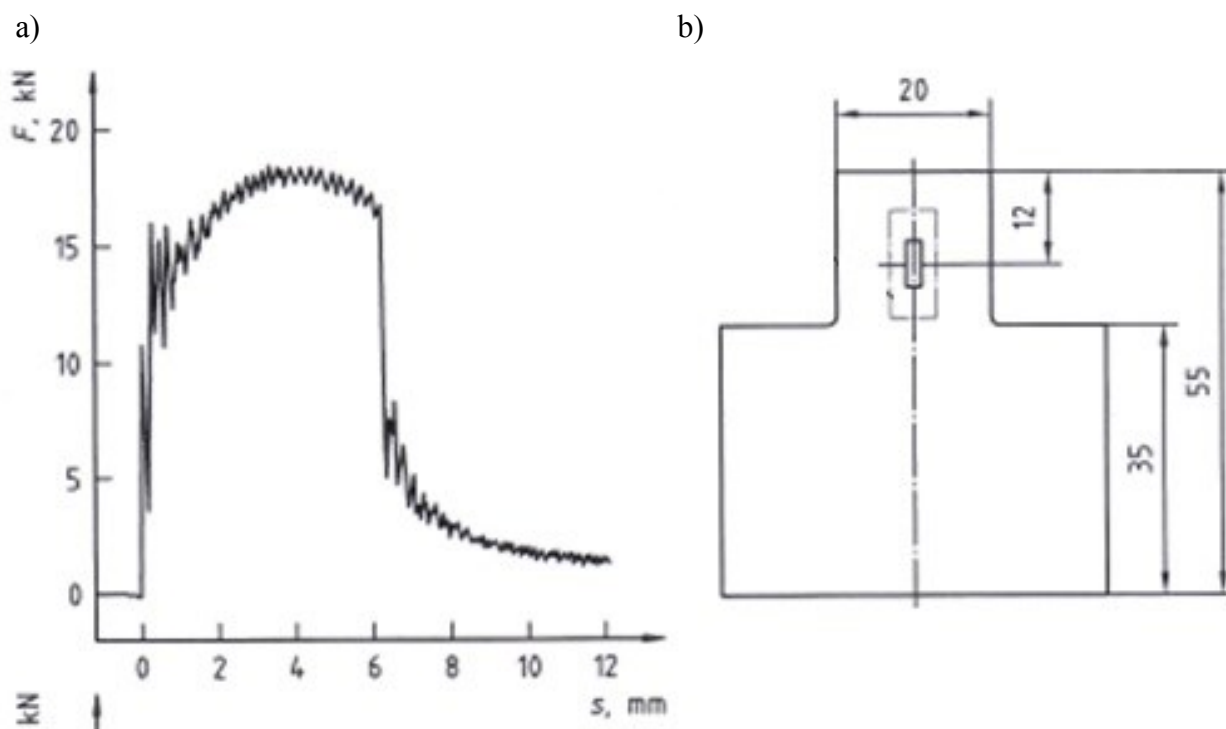


Figure 2. a) Force-displacement curve, b) sketch of the instrumented knife [6].

MECHANICAL TESTING OF STEEL S275J0

Mechanical properties of steel S275J0 were tested in the experimental part of the work. Static tensile testing and Impact test on instrumented Charpy hammer with the load-displacement diagrams were carried out. The main objective of the research was to compare the results of forces obtained by the static tensile tests and instrumented Charpy.

INSTRUMENTED CHARPY IMPACT TEST

Tests were carried out on five specimens with standard sizes of $55 \times 10 \times 10 \text{ mm}^3$, V-notched depth of 2 mm, made at angle of $45^\circ \pm 2^\circ$. All measurements were within the limit values defined in the standard ISO 148-1. Instrumented Charpy hammer was used with following data (Figure 3): Manufacturer-Zwick/Roell, type: RKP 450, measuring range of device: from 0 J to 450 J, digital readout on PC with resolution of 0,01 J.

The test results are shown in a diagram (Figure 4) for sample 1, which shows that the absorbed impact energy is 185,35 J.

Furthermofre, two different forces are shown in diagram:

- yield force (F_{gy}) is determinated on the intersection of the growing part of the second peak of the curve and conlinear regression line through an oscillating curffe force-displacement which amounts 9947,03 N,
- maximum force (F_m) is defined as maximum value on the curve, that is 15350,27 N.

Accompanied absorbed impact energies are shown in Table 1.

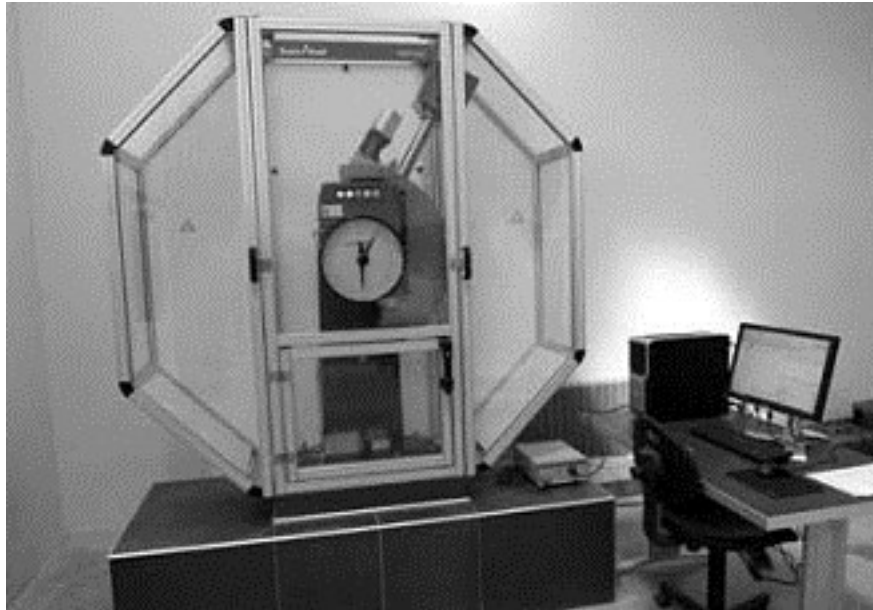


Figure 3. Instrumented Charpy testing machine RKP 450.

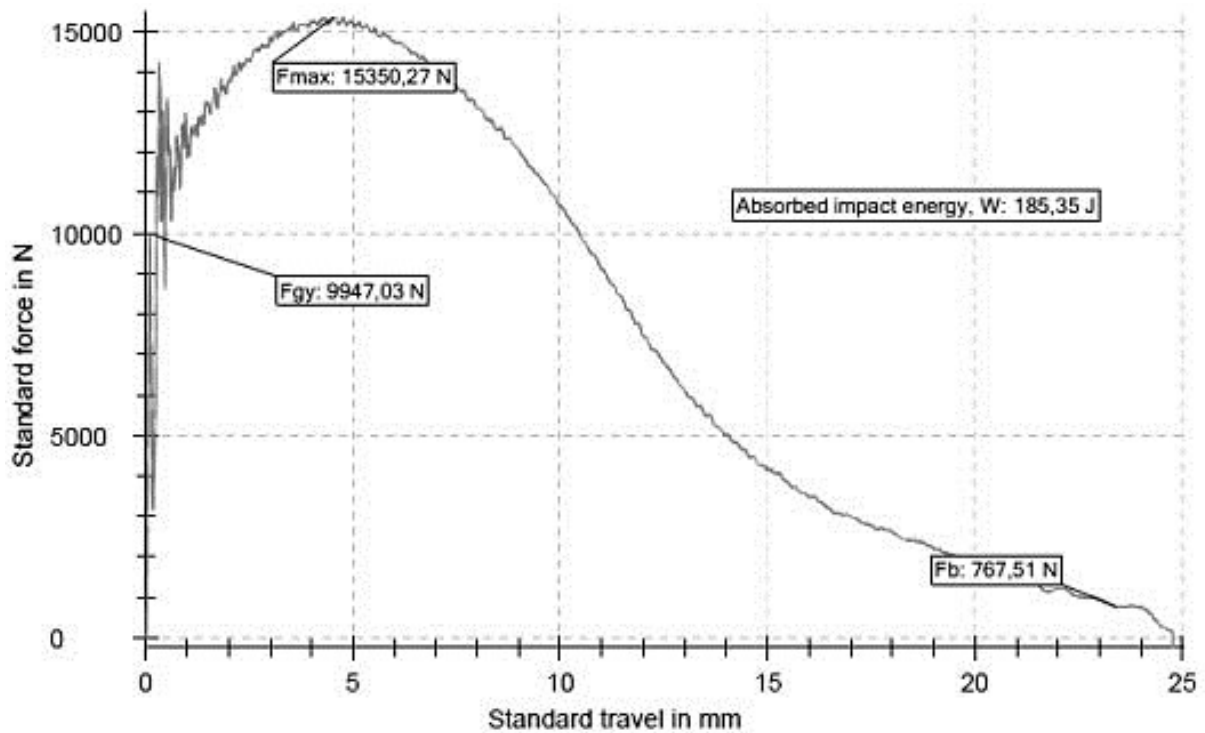


Figure 4. Results of instrumented Charpy test for sample 1.

Table 1. Results of instrumented testing.

Sample	KV, J	F_{gy}, N	F_m, N
1	185,35	9 947,03	15 350,27
2	185,50	8 763,45	15 304,72
3	174,50	9 936,09	15 379,92
4	187,01	10 030,71	15 305,87
5	172,40	9 963,41	15 563,96
Average	180,95	9 728,14	15 380,95
Standard deviation	6,19	483,46	95,79

STATIC TENSILE TEST

Static tensile test was carried out on a test machine with the following data: Manufacturer: Heckert, type: WPM EU 40 MOD, accuracy class: 0.5 (according to DIN EN ISO 7500-1). The test was carried on five specimens of round cross-section made from the same steel as the specimens for impact test. Specimens are shown in Figure 5.

Results of static tensile tests (maximum force – F_m , yield force – F_{eH} , force at break – F_k , yield strength – R_{eH} , tensile strength – R_m , elongation – A , contraction – Z) are shown in Table 2.

The initial diameter of the specimens was 6 mm and the gauge length was 30 mm. Deviations in size and shape of specimens were within the allowable values according to DIN EN ISO 6892-1. The temperature during the test was 22,8 °C, and the loading rate was 5 N/mm² s⁻¹. Force-elongation diagram of sample 1 is shown in Figure 6.



Figure 5. Specimens for static tensile test.

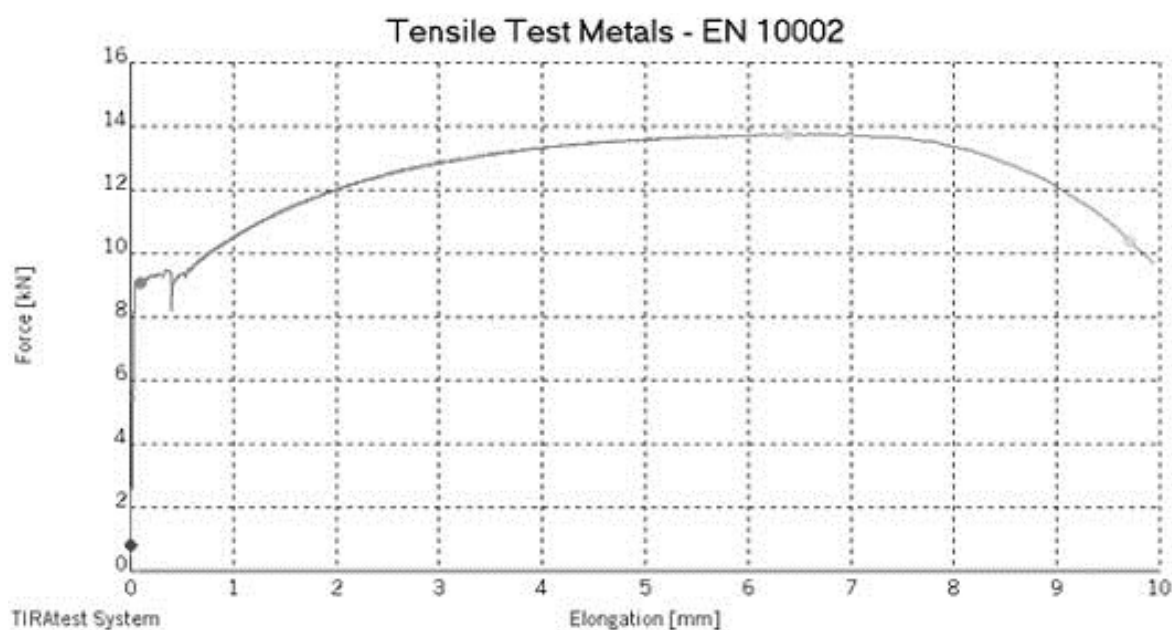


Figure 6. Diagram force-elongation for sample 1.

Table 2. Results of static tensile tests.

Sample	F_{eH} kN	F_m kN	F_k kN	R_{eH} N/mm ²	R_m N/mm ²	A %	Z %
1	9,37	13,74	10,25	331,40	485,9	34,1	69,2
2	9,57	13,84	10,40	336,15	486,1	37,0	71,6
3	9,50	13,82	10,10	333,90	485,4	36,9	71,7
4	9,47	13,64	10,05	335,17	482,5	35,0	71,6
5	9,32	13,56	9,87	329,80	479,7	36,4	71,6
Average	9,45	13,72	10,13	333,30	483,9	35,9	71,1
Standard deviation	0,09	0,11	0,18	2,36	2,48	1,14	0,97

RESULT ANALYSIS

The purpose of the research was to determine whether there is a correlation between test results obtained by instrumented Charpy method and static tensile testing. By visual comparison of diagrams force-displacement and force-extension (Figures 4 and 6) it can be conclude that there is a correlation between these two diagrams.

The analysis of the yield force from static tensile test (F_{eH}) and yield force from Charpy instrumented test (F_{gy}), diagram in Figure 7, shows that these values are approximately equal. A noticeable effect is that the repeatability is better for static tensile test.

The analysis of maximum forces at static tensile test (F_m) and the maximum force at Charpy instrumented method (F_{m-Ch}) shown in the diagram (Figure 8) It is evident that there is a difference between these values. Reproducibility of results is in this case is much better and it is equal for both test methods.

By comparing the arithmetic values of force (Figure 9) it is noticeable that the differences are very small. For the force at yield point, this difference is about 3 % and for the maximum force it is about 12 %.

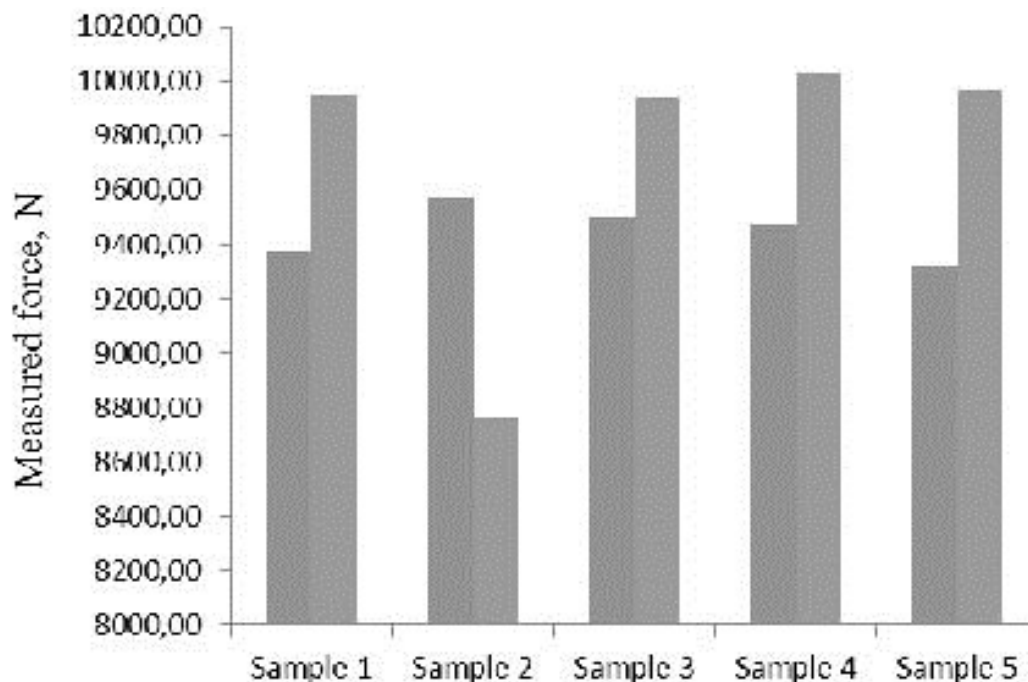


Figure 7. Diagram of the forces F_{eH} i F_{gy} . Left bar for a sample denotes F_{eH} and right F_{gy} .

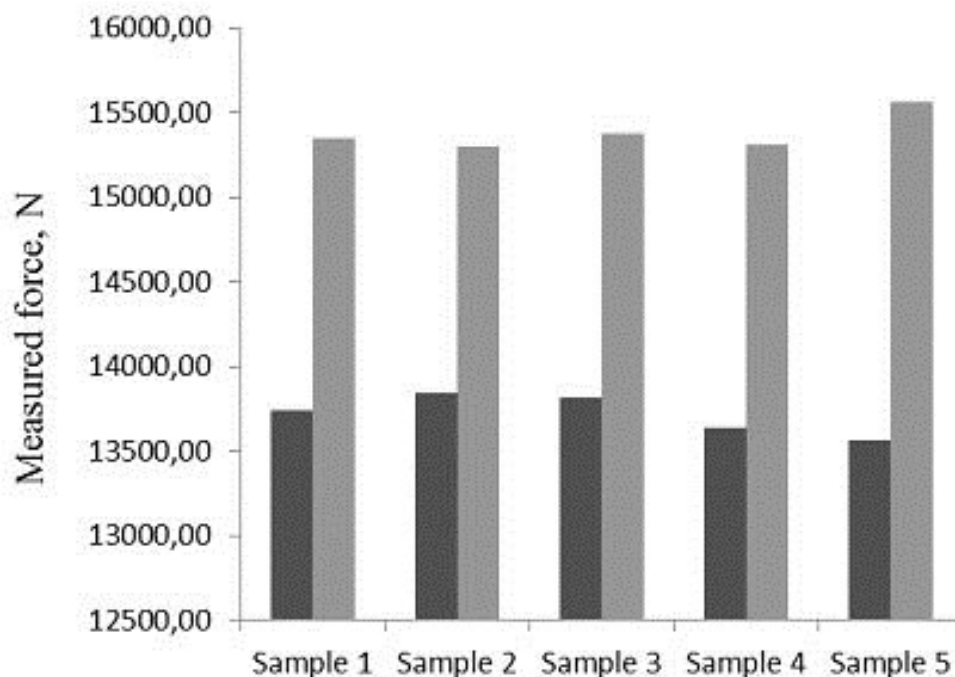


Figure 8. Diagram of the forces F_m i F_{m-Ch} . Left bar for a sample denotes F_m and right F_{m-Ch} .

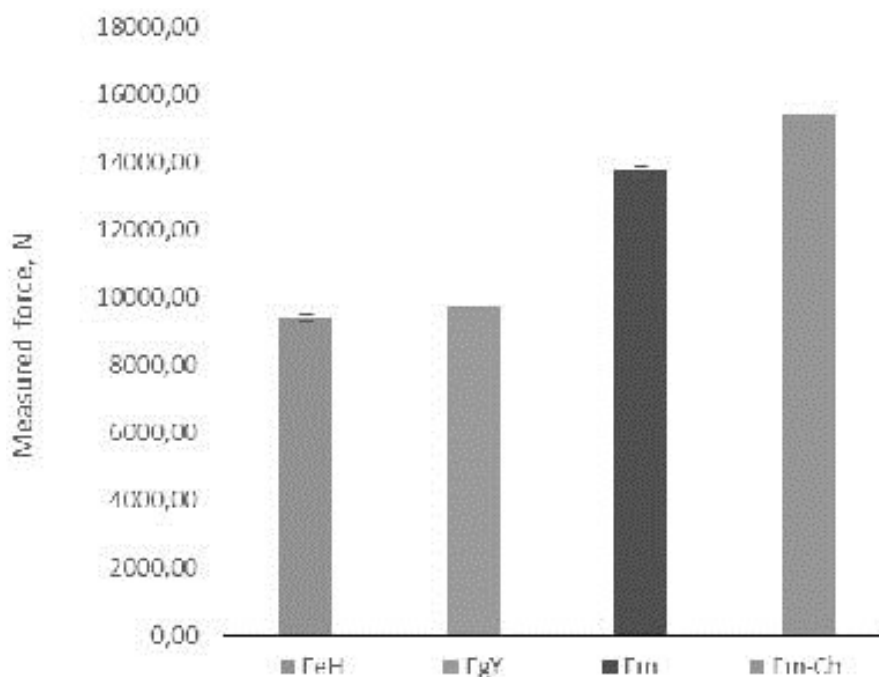


Figure 9. Show of the arithmetic values of the force.

Considering that this is a different type of load it is clear that there is some correlation. If all the influential factors were added to testing and evaluation of measurement containing the uncertainty of measurement, the correlation could be confirmed better.

CONCLUSIONS

With the usage of instrumented Charpy impact test, except the results of absorbed impact energy, more important pieces of information about the material are obtained. Experimentally obtained results make possible reaching certain conclusions.

Based on the force-displacement diagram of the instrumented Charpy method it is plausible to reveal amounts of forces that are characteristic for the static tensile testing. On the basis of tests on S275J0 steel it is shown that yield forces of instrumented method coincide with the values of the forces at the yield point of the static tensile test.

Maximum forces vary around 10 %. Determination of the force at the end of unstable crack and force at the beginning of the crack is problematic because they depend on the type of curves gained from the instrumented Charpy method and in this case it was not possible to connect them with the values from static tensile test. In order to obtain more reliable results, it is necessary to carry out a larger number testing. Additionally samples should be made more uniform, that primarily refers to the angle at V notch with test samples for impact test.

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