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INFLUENCE OF THE CUTTING DIRECTION OF THE CHARPY SPECIMENS FROM THE STEEL 10GN2MFA ON THE COMPONENTS OF THE FRACTURE ENERGY AND THE DUCTILE-TO-BRITTLE TRANSITION TEMPERATURE

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Summary. *The Charpy specimens impact tests are one of more simple and inexpensive methods to determine the mechanical properties of materials. The results of these tests can be used to estimate the strength and durability of large-scale structures. A series of the Charpy specimens impact test from high-alloyed high-temperature resistant steel10GN2MFA were carried out in the temperature range of –130 ÷ +70ºC with control of cutting direction. The tests were conducted on instrumented vertical impact machine, which can record a full diagram of specimen's deformation and fracture. The values of total energy of deformation and fracture and its components: energy of crack initiation, energy of ductile crack growth, brittle cracks energy and ductile rupture energy were determined. It was found, that ductile-brittle transition temperature for specimens cut in longitudinal direction (group GK) is higher than for specimens cut in transversal direction (group GO). It is shown, that the cutting direction of Charpy specimens significantly influences the values of total energy of deformation and fracture and its components, and the values of the ductile-brittle transition temperature for 10GN2MFA steel.*

Key words*: Charpy specimen, cutting direction, energy of deformation and fracture, ductile-brittle transition temperature.*

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Statement of the problem. The world experience shows, that the standard basis available in Ukraine needs improvements for more correct interpreting of strength and durability of the nuclear power-station 1-st contour elements. Nowadays different numerical and experimental methods are being developed and improved for solving the problems of broadening the power-stations equipment operation life looking for the additional margin of safety.

While calculating the brittle fracture resistance it is necessary to know the value of the critical brittleness temperature T_{k0} of the material in the initial state in order to build the curve of the permissible values of the stress intensity factor (SIF). Usually T_{k0} is found according to the results of the impact tests of the Charpy specimens, the methods of finding T_{k0} and other factors affecting the value of T_{k0} being of special attention nowadays. The result of the bending tests of the specimens with concentrators differ from those cut in the longitudinal and transversal directions. That is why the investigation of the effect of the cutting direction of the Charpy specimens and the cut orientation on the results of the impact tests, as well as the determination of the critical brittleness temperature, are the pressing problems.

Analysis of the available results of investigations. The authors [1] confirm the strong difference between the transversal and longitudinal properties while impact bending testing of specimens with the concentrator on the contrary to the static testings. Because of that the construction conditions for choosing materials for special structures the requirements standards of the specimens impact brittleness cut in both transversal and longitudinal directions are introduced.

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In the paper [2] it is shown, that the available stress concentrator, as well as the dynamic nature of loadings during impact bending testing, often result in the more clear appearance of the metal anisotropy. Therefore, under the equal values of the ultimate strength in the transversal and longitudinal directions the impact brittleness of the transversal specimens from steel 30ChGSA can be in three times lower, than those from the longitudinal ones.

The fibre microstructure does not affect the ultimate strength, yield and proportion, but is sufficient on the impact brittleness, transversal reduction, elongation and ultimate durability [3]. These characteristics are improved along the fibre and get worse in the transversal direction. If the temperature curves, which specify the dependence of the impact brittleness of the steel 09G2S on the rolling direction, are compared, it is seen, that the impact brittleness in the circle direction (axis crack) decreases by 20 – 30% in comparison with the longitudinal one (circle crack). Thus, the other characteristics obtained from the impact tests, such as ductile-to-brittle transition temperature, critical value of the *J*-integral, etc., can differ greatly.

The Objective of the paper is the investigation of the cutting direction of the Charpy specimens from steel 10GN2MFA and the cut orientation on the energy characteristics of fracture and the ductile-to-brittle transition temperature.

Statement of the task. In the paper in question the impact tests were carried out on the instrumented vertical impact machine [5] equipped with the multi-channel system of the power recording (discretization frequency 20 MHz), the system of heating and cooling of specimens within the broad range of temperatures [6]. The standard Charpy specimens of 55 x 10 x 10 mm [7,8] were tested. The tests were carried out within the temperature range -130 ÷ +70 ˚C at the impact velocity V_0 = 4,4 m/sec. The standard Charpy specimens from the steel 10GN2MFA (Fig. 1) were made for the tests.

The steel 10GN2MFA is used for the production of steam generators, pressure compensators, main central pipeline (MCP) and other elements of the 1^{-st} contour equipment elements of the nuclear power plants, which operate under high temperature and pressure. The Charpy specimens were made of the main metal from the acceptance of a control weld of the MCP part ø990×70 in the initial state.

To investigate the circle and axis crack propagation the specimens cut in two directions – longitudinal and transversal, as it is shown in Fig. 2, were cut.

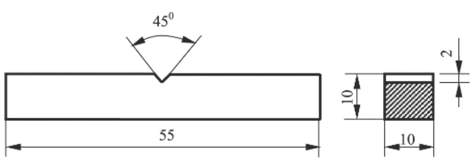

Figure 1. Standard Charpy specimen

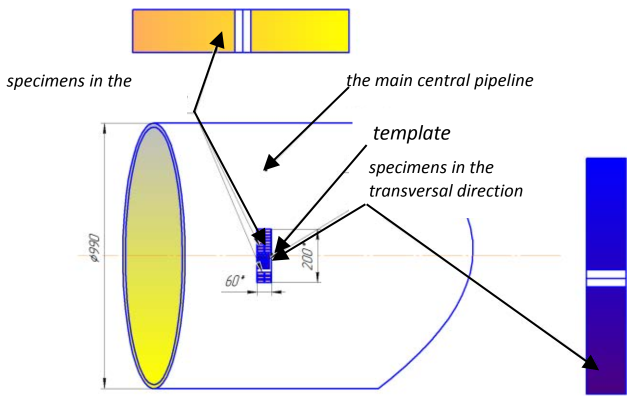

Figure 2. Scheme of cutting specimens from the part of the MCP

On the specimens cut in the longitudinal direction the circle crack propagation (the specimens group was marked GK) was investigated, and on the specimens cut in the transversal direction the axis crack propagation (the specimens group was marked GO) was investigated.

Analysis of the results of investigation. The carried out impact bending tests of the standard Charpy specimens from the steel 10GN2MFA made possible to determine the characteristics of the crack propagation in two directions.

The diagrams of deformation and fracture P(t). In Fig. 3 – 6 the diagrams of the load change on the time P(t) are presented, which were obtained according to the results of the two type specimens tests. It is seen (Fig. 3), that the fracture of two specimens types at the test temperature -120 ºC is of the brittle nature, here the specimens with the circle crack fracture energy being of much higher value. At the tests temperature -50 ºC (Fig. 4) the brittle fracture of the GO specimens occurs, at the same time on the diagram of the GK specimens fracture the area of the ductile crack growth, the area of the crack brittle growth, as well as the area of the crack rupture energy, are clearly seen. According to the Fig. 5 at the temperature 0ºC the GO specimens have a small area of the crack brittle growth, at the same time the GK specimens are of the totally ductile fracture-type nature. At the temperature 50 ºC both groups of specimens are of the ductile-type fracture.

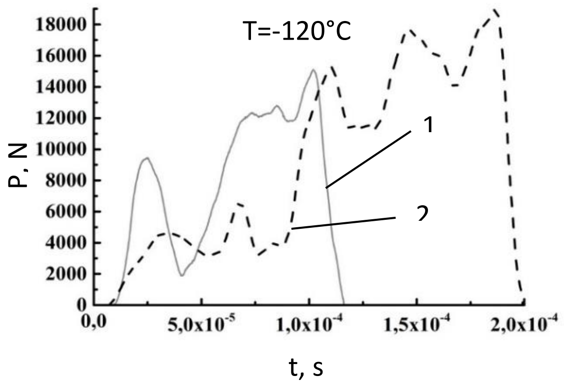

Figure 3. Diagrams of the specimens deformation at the temperature -120°C: 1 specimens of the GO group, 2 specimens of the GK group

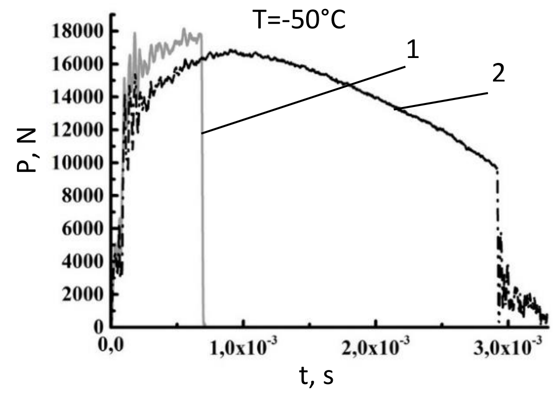

Figure 4. Diagrams of the specimens deformation at the temperature -50°C: 1 specimens of the GO group, 2 specimens of the GK group

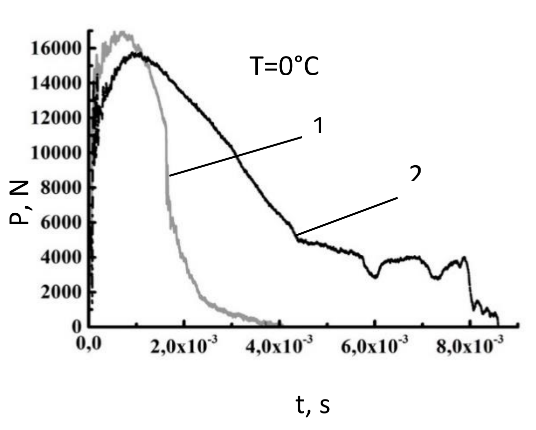

Figure 5. Diagrams of the specimens deformation at the temperature 0°C: 1 specimens of the GO group, 2 specimens of the GK group

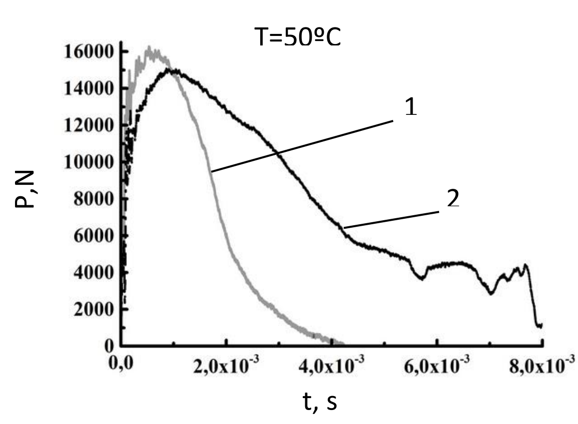

Figure 6. Diagrams of the specimens deformation at the temperature 50°C: 1 specimens of the GO group, 2 specimens of the GK group

Determination of the energy of deformation and fracture. The nature of the specimens fracture changes depending on the tests temperature and the deformation rate. High sensitivity of the recording system makes possible to separate the load diagram into the characteristic areas to calculate the values of the total energy of deformation and fracture E_t and its components: the energy of the crack initiation E_{init}, the energy of the crack ductile growth $E_{d.c.g.}$, the energy of the brittle crack growth E_b and the energy of the ductile rupture $E_{d.r}$ (Fig.7) [9]. Here it was assumed, that the crack initiation is at $P=P_{max}$. The values of the total energy of deformation and fracture, as well as its components, were found according to the standard ISO 14556 [7], which deals with the transformation of the diagram P(t) into P(s).

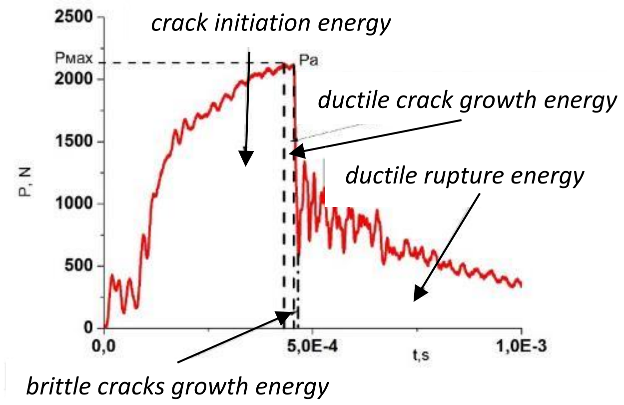

Figure 7. Separation of load diagram P (t) into the characteristic areas

In Fig. 8 – 11 the graphs of the temperature dependences of the total energy and its components for two groups of specimens are presented.

The GK group specimens are characterized by more high crack initiation energies and the rupture energies, as it is shown in Fig. 8, 11. The GO group specimens are characterized by more high crack propagation energies in the area of the crack stable growth and the crack propagation in the areas of the brittle growth, as it is shown in Fig. 9, 10.

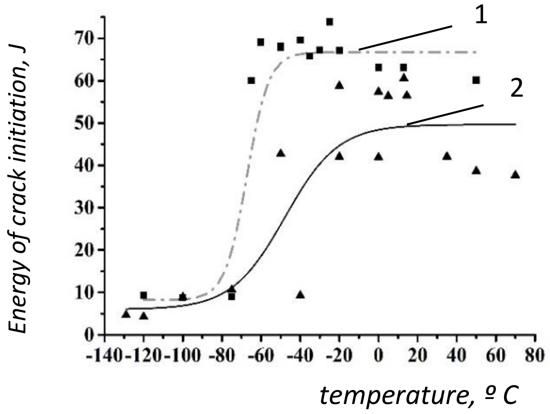

Figure 8. Temperature dependence of the crack initiation energy: 1- specimens of the GK group, 2- specimens of the GO group

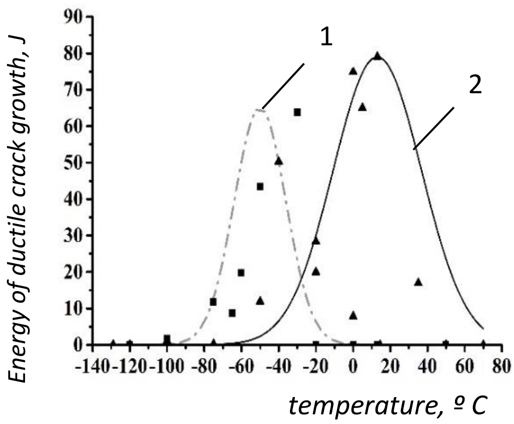

Figure 9. Temperature dependence of the ductile crack growth energy: 1 specimens of the GO group, 2 specimens of the GK group

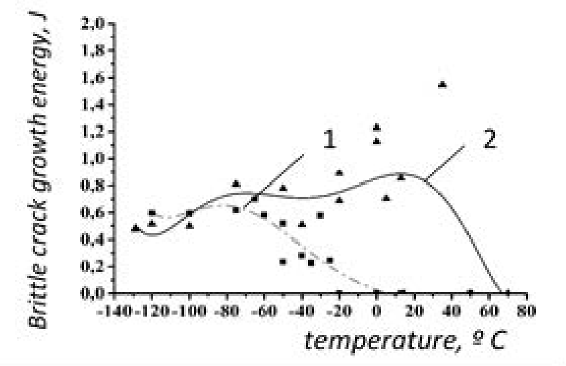

Figure 10. The temperature dependence of the brittle crack growth energy:1- specimens of the GK group, 2- specimens of the GO group

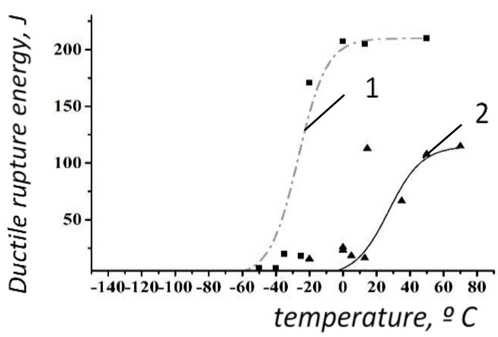

Figure 11. Temperature dependence of the ductile rupture energy: 1- specimens of the GK group, 2- specimens of the GO group

The diagram of dependence of the fracture energy on the temperature for the standard Charpy specimens, as well as for all materials with the volumetric crystal lattice (VCL) [10] looks like the sigmoidal curve with the clearly seen lower and upper shelfs. As it is seen in Fig.12 the lower shelf energies are almost of the same values, at the same time the energies of the upper shelf being of great differences. Thus, the energy of the upper shelf for the specimens with the circle crack are by 40% higher, than those for the specimens with the axis crack.

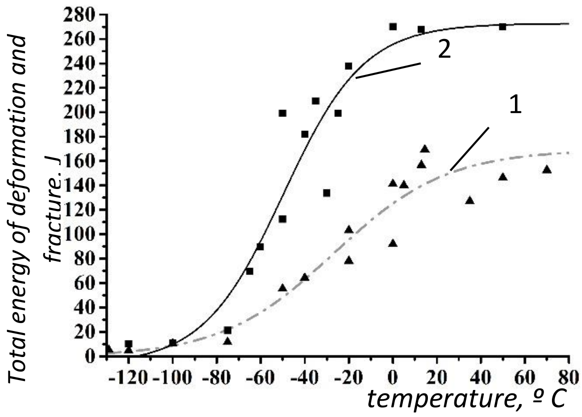

Figure 12. Temperature dependences of the total fracture energy: 1- specimens of the GK group, 2- specimens of the GO group

Fractography investigations. According to the fractography investigations of the fracture surfaces the relations between the characteristic zones were found. In Fig. 13 – 15 the graphs of temperature dependences of the percentage of the characteristic fracture area of the Charpy specimens are presented.

The analysis of the fracture area of the Charpy specimens showed, the GK group specimens are of greater square of the stable growth area in comparison with those of the GO group. (Fig. 13), but of the smaller rupture percentage (Fig. 15). Therefore, the brittle growth area of the GK group specimens is located much more far from the concentrator, which testifies more later brittle crack initiation in comparison with the GO group specimens (Fig. 16, 17).

Here the square of the brittle fracture area for the specimens of both GK and GO groups, in fact, do not differ at equal temperatures (Fig. 14).

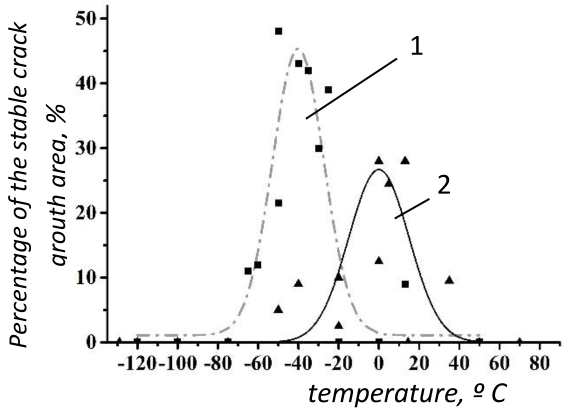

Figure 13. Dependence of the percentage of the stable crack ductile grouth area on the temperature: 1 specimens of the GK group, 2 specimens of the GO group

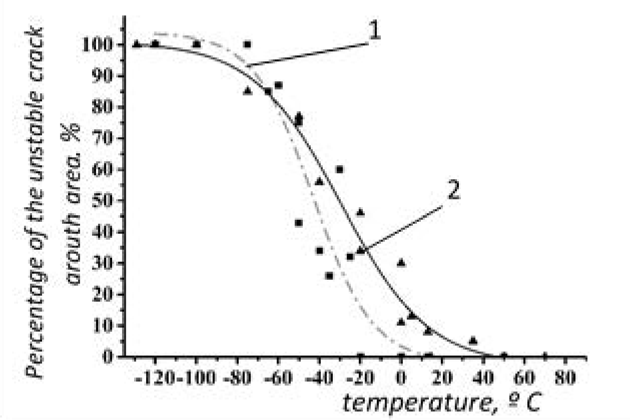

Figure 14. Dependence of the percentage of the brittle crack grouth area on the temperature: 1 specimens of the GK group, 2 specimens of the GO group

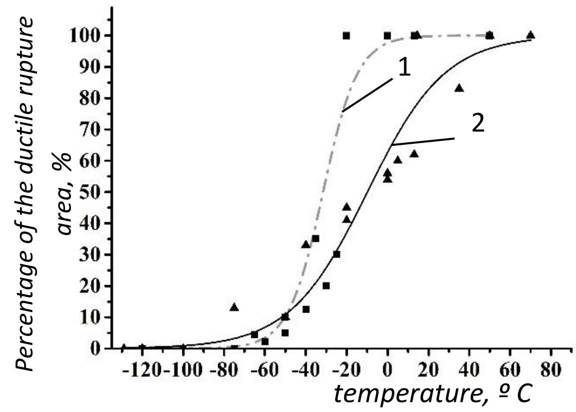

Figure 15. Dependence of the percentage of the ductile rupture area: 1 specimens of the GK group, 2 specimens of the GO group

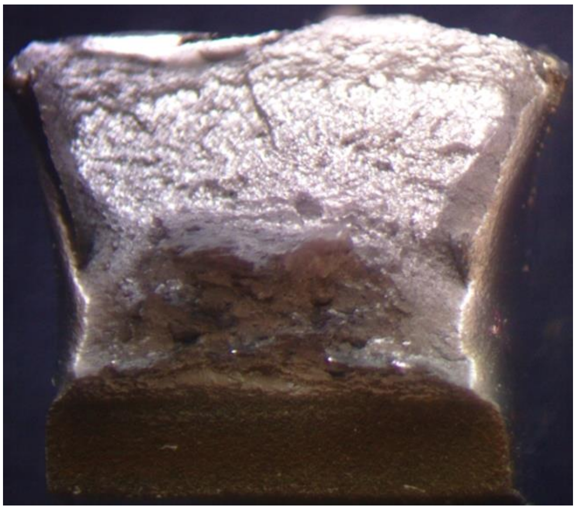

Figure 16. Fracture surface of the specimen from steel 10GN2MFA with a concentrator of circular direction (group GK) at temperature -25°C

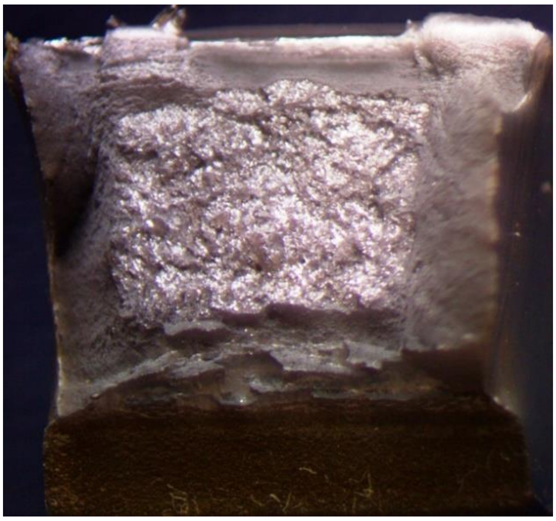

Figure 17. Fracture surface of the specimen from steel 10GN2MFA with a concentrator of axial direction (group GO) at temperature -25°C

Determination of the ductile-to-brittle transition temperature. Basing on the fractography investigations of the fracture surfaces of the both group specimens the estimation of the ductile fracture component was carried out. According to the obtained diagrams the specimen fracture ductile component dependence on the temperature and the temperature dependence of the fracture energy the first critical temperature of brittleness was estimated, at which the percentage of the ductile component in the fracture is equal to 50% of all the fracture square $T_к = T_{50\%}$ [10] (Fig.18). For the specimens cut in the longitudinal direction $T_{50\%}$ = -40.4 °C. For the specimens cut in the transversal direction $T_{50\%}$ = -31.2 °C.

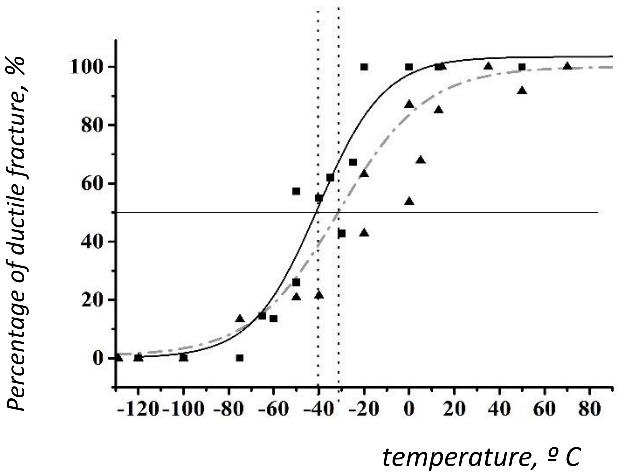

Figure 18. Temperature dependence of the percentage of ductile fracture for two specimen groups from steel 10GN2MFA

Thus, for the steel 10GN2MFA the cutting direction of the Charpy specimens affects sufficiently the value of the fracture energy of the specimens and its components, as well as the value of brittleness critical temperature.

Conclusions. The impact tests of the standard Charpy specimens from the steel 10GN2MFA cut in two directions-longitudinal and transversal, at different temperatures on the instrumented vertical impact machine, were carried out. According to the test results the temperature dependences of the total energy of deformation and fracture, as well as its components, were built. According to the fractography investigations the temperature dependences of the ductile component of the two group specimens fracture, were obtained and their comparison was made. It was shown, that the cutting direction of the Charpy specimens affects sufficiently the value of the energy of the specimens fracture and its components, as well as the value of the brittleness critical temperature for the steel 10GN2MFA.

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УДК 539.4

ВПЛИВ НАПРЯМКУ ВИРІЗКИ ЗРАЗКІВ ШАРПІ ЗІ СТАЛІ 10ГН2МФА НА СКЛАДОВІ ЕНЕРГІЇ РУЙНУВАННЯ ТА ТЕМПЕРАТУРУ В'ЯЗКО-КРИХКОГО ПЕРЕХОДУ

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Резюме. *Проведено ударні випробування стандартних зразків Шарпі зі сталі 10ГН2МФА, вирізаних у двох напрямках – поздовжньому та поперечному, за різних температур на інструментованому вертикальному копрі. За результатами випробувань побудовано температурні залежності повної енергії деформування, руйнування та її складових. За результатами фрактографічних досліджень отримано температурні залежності питомих енергій на різних ділянках поверхні зламу та проведено їх порівняння для двох груп зразків. Визначено критичні температури крихкості.*

Ключові слова: *зразок Шарпі, напрямок вирізки, енергія деформування та руйнування, температура в'язко-крихкого переходу.*

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