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# Contact-Resistance Assessment of the Stress-Strain Condition of Welded Joints

**Abstract:** NDT-related diagnostics have triggered renewed popularity of the contact-resistance method indicating linear dependence between the electric resistance of metals and tensile stress having significant resistance sensitivity. The contact-resistance method enables the indication of a moment where elastic stresses transform into plastic stresses and can also be used to detect welding imperfections.

**Keywords:** NDT, contact-resistance method, welded structure, weld, tensile stresses, resistance of deformed metal

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Issues related to the improvement of methods and equipment enabling the assessment of various internal stresses of metals subjected to technological treatments remain relevant.

The most popular methods used when assessing internal stresses in welded joints include the electron spectral interferometric method [1]. Defectoscopic tests and evaluation of welded structure service life involve the use of diagnostic equipment utilising acoustic emission, ultrasonic inspection, tomographic flaw detection with subsequent analysis of parameters of elastic wave pulse spectra, ferromagnetic flaw detection, electric resistance strain gauge measurements, sonic speed-related dependences used in assessments of the stress-strain condition of metals and other methods [2÷5]. The diagnostics of structures of critical importance used in nuclear power engineering, shipbuilding industry, rail transport and aviation involves the use of the eddy-current method [6÷8].

Advantages of the eddy-current method include the possibility of assessing metal condition in the most exposed surface layers (e.g. when locating corrosion centres), simplicity, operational comfort and relatively low equipment-related costs. However, the above-named method cannot be used for the identification of internal stresses in metals (generated both at the manufacturing stage and in operation). Mechanical stresses in materials are measured using the extensometric method, the essence of which consists in changes in the specific resistance of the extensiometer material during its deformation induced by changes in interatomic distances, concentration of charge carriers and many other processes. The above-named processes partly represent phenomena occurring in the test metal and, similar to most indirect measurement methods, are characterised by low sensitivity in comparison with other strain measurement methods [9].

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Because of the foregoing, direct measurements of the local resistance (*the terms of "local resistance" was used in the study because of differences in methods used for resistance measurements in comparison with the method enabling the measurement of "specific resistance"*) of a metal enable the obtainment of more reliable information about its condition through the possibility of recording macro and microimperfections generated during metal deformation and impossible to detect using electric resistance strain gauge measurements.

For the first time, an attempt to identify structural changes in metals through resistance measurements was successfully performed half a century ago [10]. The present development of the research is discussed in works [11, 12].

The primary possibility of the practical use of the contact-resistance method was verified experimentally using specimens made of steel 09ХГСЮЧ (09 – carbon, Х – chromium, Г – manganese, С – silicon, Ю – aluminium and Ч – rare-earth elements) (12x2 mm in cross-section) situated between supports located at a distance of 60 mm in a three-point bending scheme, the purpose of which was to trigger tensile stresses. The bending of the specimen was recorded using a dial gauge with a scale interval of 10 μm. The values of specimen resistance between gauge fixing points, situated at a distance of 10 mm, were read out using the scale of micrometer M246. To stabilise the value of resistance in the zone of contact between measurement sensors and the specimen metal, the joint was made (using spot braze welding) on the side of the specimen where tensile stresses were generated.

The test results concerning the assessment of changes in steel resistance in relation to tensile strength, performed using a ZDM10 testing machine, confirmed the linear dependence between the above-named parameter and changes in mechanical stresses up to the yield point. The correlation between resistance and mechanical stresses in the test specimen can be expressed in Ohm units or in conventional units proportional to resistance expressed in Ω.

An exemplary correlation obtained for resistance expressed in conventional units is presented in Figure 1 as the result of an experiment performed using specimens made of steel 15ХСНД (15HSND); the specimens were 160 mm long and the dimensions of their rectangular section were 6×12 mm. The middle part of the specimen was provided with measurement sensors of a micrometer similar to the design of micrometer M246. Related indications were displayed on a digital monitor of a standard multimeter. The changes in the resistance of the middle segment of the specimen (expressed in conventional units) using tensile tests are presented in Table 1.

Table 1. The changes in the resistance of the middle segment of the specimen using tensile tests

| Stage no. | Time, h, min, s | Load, N | Resistance, Ω | Stress, MPa |
|---|---|---|---|---|
| 2053 | 16.45.04 | 150 | 28.6 | 20.8 |
| 2054 | 16.45.22 | 295 | 29.0 | 40.9 |
| 2055 | 16.45.26 | 315 | 29.0 | 43.7 |
| 2056 | 16.45.32 | 525 | 29.0 | 72.9 |
| 2057 | 16.45.36 | 775 | 29.3 | 107.6 |
| 2058 | 16.45.40 | 1250 | 29.8 | 173.6 |
| 2059 | 16.45.44 | 1700 | 30.2 | 236.1 |
| 2060 | 16.45.46 | 2450 | 30.2 | 340.3 |
| 2061 | 16.45.50 | 3200 | 30.1 | 444.4 |
| 2062 | 16.45.52 | 3950 | 29.8 | 548.6 |
| 2063 | 16.45.56 | 4700 | 29.5 | 652.8 |

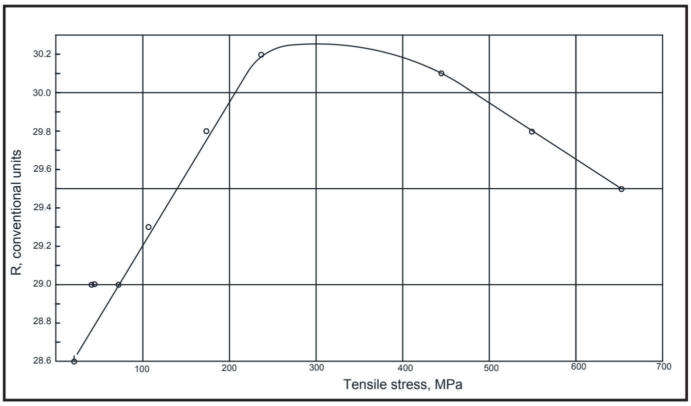

Fig. 1. Dependence of changes in the resistance of specimens made of steel 15ХСНД (15HSND) in the function of tensile stresses

The relative sensitivity of the contact-resistance method in measurements of the stress-strain condition of metals appears very promising as regards the significant improvement of the above-named parameter if supported by more advanced measurement methods and equipment.

Nearly all of the obtained diagrams of $R = f(\sigma)$ were characterised by the presence of the fragment where the resistance curve changed from rising into falling, which coincided with the formation of the plasticisation area on the diagram concerning the tension of the test specimen. The above-presented peculiarity of the contact-resistance method for assessing the stress-strain condition of metals makes it possible to diagnose the condition of stored and operated welded structures. It should be noted that crack may also develop after the performance of quality control by the manufacturer.

In addition to increasing interatomic distances and density of imperfection in metal, correlation $R = f(\sigma)$ on the segment of the increase in metal resistance during deformation triggered by tensile loads can also be hedged by opening out microcrack nuclei and by the course of a number of other processes.

However, the clarification of the decrease in resistance following the obtainment of a certain degree of deformation (after reaching the yield point) and principles governing the above-named decrease require further research, undoubtedly important both in scientific and practical terms. The clarification of the decrease in resistance at the metal plasticisation stage could involve the assumption concerning the stepped development of plastic strains demonstrated by the Lüders–Tschernov slip bands.

Taking into consideration the fact that internal mechanical stresses favour the formation of microcrack nuclei, the primary function of the contact-resistance method is not only to determine the level of mechanical stresses but also to identify nuclei of microcracks at their initial development stage, and not while transforming from micro into macrocracks as this can be recorded using other methods. In addition to assessing internal mechanical stresses in metals, the contact-resistance method can also be used in defectoscopic tests, e.g. in non-destructive tests of spot resistance welds.

The experiment presented below involved three stages:

1. making of overlap joints using various parameters of spot resistance welding (welding times of 40 and 80 ms, constant electrode force and welding current);
2. measurements of resistance (electric conductivity) of the spot weld;
3. determination of the tensile strength of the welded joints performed using a ZDM-4 testing machine.

The results of measurements related to the resistance of specific welds (see Table 2) and related tensile strength of the welded joint (Table 3) justify the statement that there is both the qualitative and quantitative correlation between the resistance of the weld and the tensile strength of the joint. Test specimens were made of steel X17H12M2 (H17N12M2) (120×25×1 mm). During welding, welds were made at an equal distance from the face and the edge of the specimens. The window located at left-hand corner of Figure 2 contains the schematic diagram presenting the measurement of spot weld resistance. To average weld resistance values, Table 2 contains results of three measurements performed at various indent spots left by the welding machine electrodes. Measurement results concerning electric parameters of the weld expressed in conventional units are presented in Table 2. The results of the tensile tests involving spot welded overlap joints are presented in Table 3. The generalisation of data presented in Tables 2 and 3, in the form of a diagram reflecting the correlation between the tensile strength of the weld formed through the two-sided overlap resistance welding of sheets and the electric conductivity of the weld, is presented in Figure 2.

Table 2. Correlation between the electric conductivity of the weld material (metal) and welding time

| **Specimen number at $t_{weld}$ 40 ms** | **Electric conductivity of the weld material (metal), Ω** | **Specimen number at $t_{weld}$ 80 ms** | **Electric conductivity of the weld material (metal), Ω** |
|---|---|---|---|
| 1 | 0.2917 | 5 | 0.1942 |
| | 0.2921 | | 0.2000 |
| | 0.3118 | | 0.1968 |
| 2 | 0.2733 | 6 | 0.1179 |
| | 0.2826 | | 0.1333 |
| | 0.2826 | | 0.1270 |
| 3 | 0.1783 | 7 | 0.0671 |
| | 0.1901 | | 0.1028 |
| | 0.1900 | | 0.9150 |
| 4 | 0.1475 | 8 | 0.0488 |
| | 0.1575 | | 0.0558 |
| | 0.1607 | | 0.0666 |

Table 3. Tensile strength of the welded joints

| **Specimen no.** | **Tensile strength at rupture *P*, kG** |
|---|---|
| 1 | 320 |
| 2 | 330 |
| 3 | 280 |
| 4 | 312 |
| 5 | 455 |
| 6 | 405 |
| 7 | 556 |
| 8 | 390 |

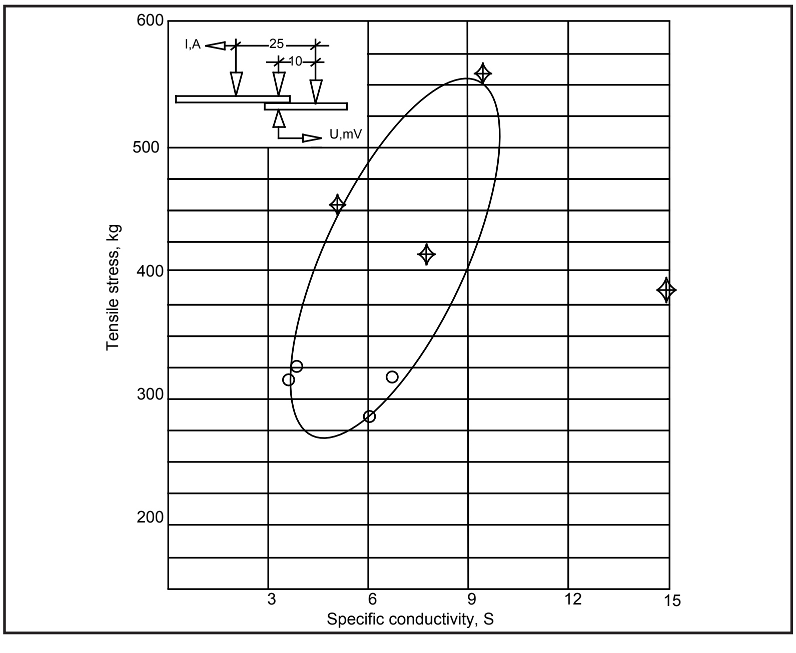

Fig. 2. Assessment of the tensile strength of the welded joint based on the factor of weld electric conductivity

The diagram reveals that when (after welding) the electric conductivity of the weld metal changes within the range of 4 to 8 S (Simens), the tensile strength of a given welded joint is likely to be restricted within the range of 300÷450 kG.

High correlation (interdependence) between the tensile strength of the welded joint and the electric conductivity of the weld was confirmed in several similar experiments. In many cases, the use of this dependence could be advantageous when clarifying welding parameters, e.g. when changing the grade of steel or its supplier.

When adjusting welding parameters, the above-presented method enabling the non-destructive testing of welded joints reduces both time and costs related to the preparation of the technological welding process, can be applied in high-volume production and provides the high and repeatable periodic quality control through the measurement of spot weld electric parameters.

The obtained test results indicate advantages concerning the development of equipment enabling the contact-resistance method-based assessment of the stress-strain condition of metals both in terms of non-destructive tests and when forecasting the failure-free period of welded structure operation.

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