Microstructure effect of weld joint heat affected zone on the temperature velocity factor of ultrasound

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Abstract. The effect of temperature on the longitudinal wave speed in the heat-affected zone of the weld joint of structural steel 20 is investigated. The heat-affected zone is the most dangerous place where the stress-strain state is realized and a gradient of physical and mechanical properties is observed. As a rule, it is in the heat-affected zone that the structures are destroyed. The structural state of the heat-affected zone has a significant effect on the temperature dependence of the elastic wave velocity. As a result of the research, numerical values of the temperature-velocity factor for longitudinal ultrasonic waves in steel 20 for the heat-affected zone and the base metal were obtained. In the future, the dependencies can be used to develop methods for determining material damage by the ultrasonic method.

1. Introduction

Operation of equipment in difficult climatic conditions of the Arctic and the Far North sets specific requirements for the diagnostics of the structural elements state using non-destructive testing methods. This is very important for welded joints. A weld-joint comprises of base metal, heat affected zone (HAZ) and weld metal. The heat-affected zone is the most dangerous place where the stress-strain state is realized and a gradient of physical and mechanical properties is observed. As a rule, it is in the heat-affected zone that the structures are destroyed. The role of microstructure on the mechanical properties of the heat affected zone is well known [1,2]. The structural state of material has a significant effect on the elastic and acoustic properties [3,4]. The change in temperature also has a significant effect on the elastic modulus of metals and their alloys [5-8]. The effect of plastic strain and temperature on the longitudinal and shear waves velocity of austenitic stainless steel AISI 321 is investigated in [9]. The effect of temperature on the elastic wave velocity in heat-affected zone has not been studied. The influence of temperature and of structural changes after welding process occurring on the elastic characteristics of the material is of great interest in scientific and applied terms.

To solve the problem of early diagnosis of the state of the material, the ultrasonic method is widely used. It is generally accepted that the temperature-velocity factor -the dependence of the elastic wave velocity on temperature for a particular material is a constant. In this paper, it is shown that the temperature-velocity factor for construction steel 20 essentially depends on the distance from the weld joint.

The purpose of this work is to investigate the dependence of the ultrasonic wave velocity on the temperature in HAZ and base metal of structural steel 20.
2. Experimental technique

The material investigated was construction steel 20. The chemical composition is (mass%): C 0.18, Si 0.24, Mn 0.45, Ni 0.05, S 0.02, P 0.01, Cr 0.055, Cu 0.1. Weld-joint was made by arc butt welding. The specimen was 100 mm in gage length, 20 mm in gage width and 10 mm gage thickness. The measurements were carried out in 4 zones, located along the sample. The width of each zone was 8 mm. The distance from the first zone to the weld bead was 2 mm.

Experiment to measure the time of propagation of longitudinal elastic waves, we used the echo-pulse method, utilizing broadband acoustic transducer V110-RM made by Olympus. The central frequency of the piezoelectric transducer was about 5 MHz, its diameter was 6 mm. Longitudinal wave propagate along the Z axis, figure 1a. The error in measurement of the wave propagation time was 2-3 ns. The sample with the sensor was placed in a cold chamber in which they were cooled at a rate of 10 K/h. During the process of cooling amplitude-time diagrams were recorded. The propagation time of ultrasonic pulses $\Delta t$ on the amplitude-time diagram was determined between the first and third reflected pulses, figure 1b. The elastic waves velocity was calculated by the formula $V = \frac{4h}{\Delta t}$, where $h = h_0 (1 - \alpha \Delta T)$, $h_0$ is the thickness measured at $T_0 = 293 K (20°C)$, $\alpha$ is the thermal linear expansion coefficient $\alpha = 11.6 \times 10^{-6} K^{-1}$, $\Delta T = T_0 - T$, $T$ - current measurement temperature.

![Figure 1. Schematic diagram of acoustic measurements (a); amplitude-time diagram of the ultrasonic impulse (b).](image)

A metallography microscope ALTAMI MET 3M was used for microstructure observation. Surface of the specimen was first mechanically polished and then chemically etched in a 5% water solution of nitric acid for a few seconds to reveal microstructure.

3. Results and discussion

The heat tints on the sample after the welding process and the microstructures of the studied zones are shown in figure 2. From the figure 2 it is clear that the HAZ is located in zones 1 and 2 and partially in zone 3. Zone 4 fully corresponds to the base metal.

The temperature dependences of the longitudinal elastic waves velocities $V$ in the temperature range $-55 ^\circ C < T < 0 ^\circ C$ are close to linear for each zones, figure 3. The velocity of longitudinal waves is higher in the HAZ than in the base metal of steel 20. The slopes and the free term of the curves depend on the distance $x$ from weld bead. The dependence of the ultrasonic velocity on the temperature can be represented as:

$$V(x,T) = k(x)T + b(x)$$

(1)

where $k$ is the temperature-velocity factor of the longitudinal waves, respectively, $k = (V - V^0)/(T - T_0)$, where $V$ is the longitudinal waves velocity at temperature $T$, respectively; $V^0$ is the longitudinal waves velocity at temperature $T_0$, respectively, and $b$ is the free term, determines the velocity at $T = 0 ^\circ C$. For zone 1 $k = -0.8 \text{ m/(s•K)}$, $b=5996 \text{ m/s}$; for zone 2 $k = -0.71 \text{ m/(s•K)}$, $b=5988 \text{ m/s}$, for zone 3 $k = -0.64 \text{ m/(s•K)}$, $b=5982 \text{ m/s}$, for zone 4 $k = -0.61 \text{ m/(s•K)}$, $b=5985 \text{ m/s}$.
Figure 2. The heat tints and the microstructure of heat affected zone (×400).

Figure 3. Dependence of the ultrasonic wave velocity on the temperature for different zones. (Distance from the weld bead to the center of the zone: z1 - 6 mm, z2 - 14 mm, z3 - 22 mm, z4 - 30 mm).

The dependence of the ultrasonic wave velocity on the temperature and on the distance from the weld bead to the center of the zone presented in Fig. 4. It is expected that the micro defects accumulation process under plastic deformation will change the surface V(x, T).

The temperature-velocity factor decreases in absolute value with distance from the weld bead, Fig.5. The relationship between the temperature-velocity factors and the distance from the weld bead is linear:

\[ k = a \cdot x + d \]  \hspace{1cm} (2)
where $a = 8 \, (s \times K)^{-1}$, $d = -0.83 \, m/(s \times K)$.

**Figure 4.** Dependence of the ultrasonic wave velocity on the temperature and on the distance from the weld bead to the center of the zone.

**Figure 5.** Relation between the temperature-velocity factor and the distance from the weld bead.

Thus, by means of ultrasonic measurements, the HAZ size of the weld joint can be determined by changing the temperature of the material.

### 4. Conclusion

Ultrasonic studies of the effect of material temperature on the longitudinal wave velocity in the heat-affected zone and the base metal of the welded joint made of steel 20 were carried out. It was found that the longitudinal wave velocity decreases with distance from the weld bead. The numerical values of the temperature velocity factor in the heat-affected zone and the main metal of steel 20 was obtained. It was found that the relationship between the temperature-velocity factors and distance from the weld bead for longitudinal waves is linear. Further it is proposed to investigate the effect of plastic deformation on the temperature velocity factor in the heat-affected zone and in the base metal.

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