Results are presented from a study of the mechanical characteristics of corrosion-resistant austenitic-martensitic aging (CAMA) steels and their welds. The study was conducted by the mechanical engineering department of the Chesa Technical Institute in Prague. The experimental study was performed mainly to determine the strength and fracture-toughness characteristics of welds of CAMA steels made by arc welding in a protective medium (IPM method) or under a flux (UF method). The empirical data is used to establish relations between fracture toughness and other mechanical characteristics.

CAMA steels are modifications of classical martensitic-aging steels (maraging steels), which are high-strength materials but lack adequate corrosion resistance. Efforts to change their chemical composition in order to improve corrosion resistance through the creation of low-carbon martensite while simultaneously increasing strength and retaining sufficient impact toughness have — along with increases in strength realized through overaging — led to the development of Cr-Ni-Mo steels with additions of aluminum, titanium, and copper. The concentrations allowable for the individual elements in order to obtain an austenitic-martensitic structure can be determined using the Potak–Sagaliev diagram [1] (Fig. 1). Here, chromium equivalents are plotted off the coordinate axes: the chromium equivalent reflecting the effect of this element on ferrite $C_{\text{eqv}}^\text{fer}$ is plotted off the horizontal axis, while the analogous equivalent reflecting the influence of chromium on the temperature corresponding to the beginning of the martensite transformation $C_{\text{eqv}}^\text{mar}$ is plotted off the vertical axis. The diagram is useful for CAMA cast steels and additionally reflects features of the corresponding welds.

In our investigation, we studied steel 03Khl0N10M2T, which has the following chemical composition, %: 0.029 C; 0.18 Mn; 0.32 Si; 0.013 P; 0.011 S; 10.43 Cr; 10.13 Ni; 2.41 Mo; 1.09 Ti; 0.35 Al; 0.037 Co. This steel corresponds to the point (+3.8; -8.4) in Fig. 1. The phase composition of the steel: roughly 75% martensite, 3% ferrite, the remainder — austenite. This composition is close to the structure of the weld metal of CAMA steel Khl5N5D2T. Results of studies of the phase composition of deformable steels 03Khl0N10M2T and 03Kh6N11M3YuT were published earlier in [2, 3].

Along with the effect of the chemical composition and purity of the metal, it is necessary to consider the effect of the welding conditions and heat-treatment regimes when analyzing the properties of welds of these steels. The literature presents some data on the effect of the welding technology on the properties of welds of CAMA steels. Most of this data applies to the case of electric-arc welding with a nonmelting electrode in argon [4, 5]. There have as yet been no analyses of the effect of different welding technologies — including laser welding and welding with an electron beam.

Welding wire was obtained from the base material (its chemical composition indicated above) by its remelting and subsequent drawing. We used 1.20-mm-diameter wire for IPM welding and a 3.15-mm-diameter wire for UF welding. Table 1 shows the chemical composition of the material of the wires.

The semifinished products used to prepare the test specimens were plates 28 and 25 mm thick, 300 mm wide, and 480 and 500 mm long. They were quenched before welding: heating to 930°C, holding for 1 h, cooling in water.

The following parameters were chosen for IPM welding in regime $S_4$: $I_{\text{wd}} = 280$ A; $U_{\text{wd}} = 26$ V; unit power $Q_{S_4} = 20.3$ kJ·cm$^{-1}$. The welding times for the individual layers of the weld: $t_{\text{wd}} = 1.45$ min for the first layer (the root was ground); $t_{\text{wd}} = 1.50-3.05$ min for layers 2-7.

The following parameters were used for IPM welding in regime $S_2$: $I_{\text{wd}} = 250$ A; $U_{\text{wd}} = 25$ V; $Q_{S_2} = 16.1$ kJ·cm$^{-1}$. The welding times: $t_{\text{wd}} = 2.15$ min for the first layer (the root was ground); $t_{\text{wd}} = 1.45-3.05$ min for layers 2-7.
TABLE 1. Chemical Composition of the Test Wires

<table>
<thead>
<tr>
<th>Welding method</th>
<th>C</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Ti</th>
<th>Co</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>UF</td>
<td>0.005</td>
<td>10.76</td>
<td>10.11</td>
<td>2.29</td>
<td>0.82</td>
<td>—</td>
<td>0.35</td>
<td>0.22</td>
<td>0.05</td>
<td>0.01</td>
<td>—</td>
</tr>
<tr>
<td>IPM</td>
<td>0.011</td>
<td>10.80</td>
<td>10.30</td>
<td>2.31</td>
<td>1.01</td>
<td>0.015</td>
<td>0.40</td>
<td>0.24</td>
<td>0.07</td>
<td>0.015</td>
<td>0.045</td>
</tr>
</tbody>
</table>

Fig. 1. Structural diagram for corrosion-resistant steels [1] in the cast and welded states.

Fig. 2. Geometry of the weld for arc welding in a protective medium (a) and under a flux (b).

Argon flow rate was 14 liter/min in both welding regimes. The welds were made in an X shape. The plates that were welded were prepared in accordance with the scheme depicted in Fig. 1a.

Figure 2b shows a sketch of the weld in the case of welding under a flux. Here, we used flux PN-42 (produced in Czechoslovakia). The following parameters were chosen for the base layer to obtain a 6-layer weld: $I_{wd} = 450$ A; $U_{wd} = 34$ V; welding rate $25$ m·h$^{-1}$; unit power $27.8$ kJ·cm$^{-1}$.

The weld root was fused over its entire length, with the slag having been completely removed. The weld was probed with X-rays while the plates were in the horizontal position. Analysis of the X-ray diffraction patterns showed that the fewest small defects were present in the case of welding under a flux. The poorest indices were obtained from IPM welding in regime S2.