NATURE OF 475-DEGREE BRITTLENESS IN STAINLESS STEELS

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Stainless chromium steels containing more than 13% C show increased strength and reduced ductility and impact toughness after prolonged heating at 425 – 520°C; the specific electric resistance and corrosion resistance are also reduced. These changes are manifested most strongly after soaking at 475°C, on account of which the phenomenon is often termed 475-degree brittleness.

Analysis of published data shows that the nature of 475-degree brittleness has not been adequately studied. In the light of this we investigated stainless steel (0.06% C; 1.50% Mn; 0.73% Si; 27.80% Cr; 9.70% Ni; 0.019% S; 0.021% P), produced by automatic multilayer surfacing under a ceramic flux.

The specimens used for impact bending tests and Menager notching were cut from the built-on metal. The micro-hardness was determined with a PMT-3 tester at a load of 50 g. At least three specimens were used for each impact test and at least 15 different determinations of their micro-hardness were made.

Figure 1 shows the variation in impact toughness of the built-on metal and microstructure of the ferrite as a function of the prolonged heating at 475°C. It is clear from the given data that in the built-on metal, 475-degree brittleness, when assessed from the variation in impact toughness and micro-hardness of the ferrite, develops at a fairly fast rate. The minimum impact toughness is attained after soaking for 50 hours. As the heating time is increased, the impact toughness and micro-hardness remain unchanged.

It should be mentioned that after 100, 250 and 500 hours heating at 455°C the ferrite microhardness readings are considerably scattered (see Fig. 1); this is due to the carbide formation which occurs at the initial stages of development of this brittleness. After 1000 hours soaking there is less scatter.

Metallographic analysis of the factors governing 475-degree brittleness shows that the ferrite phase when electrolytically etched with oxalic acid exhibits heightened etchability and takes on a brown hue. When sections which have not been heated are etched in the same way, the ferrite areas turn bluish-gray.

At the initial stages of development of 475-degree brittleness an excess phase is precipitated along the boundaries of the ferrite areas and coagulates there (Fig. 2b).

It should be mentioned that the precipitation of the excess phase starts as early as 100 hours heating at 455°C. This occurs as a result of the formation of a metastable phase having a high solubility of carbon at this temperature. This phase is etched out more strongly by electrolytically etched with oxalic acid, and after precipitation only, in addition to the phase itself, etched areas where it is

* The structure of the metal contained 65% α-phase.
located can be detected. At later stages we also find the precipitation of carbide particles within the ferrite areas (Fig. 2c).

It should be pointed out that in the regions next to the earlier deposited carbide phase no carbides are formed.

As the duration of the heating is increased above 500 hours, the amount of carbide phase is appreciably reduced, and after 1000 and 1500 hours, this phase is not found at all in the polished metal (see Fig. 2c). This suggests that at certain stages of the development of the processes causing 475-degree brittleness, the carbide phase goes into a solid solution.

Experiments show that no σ phase is detected in the embrittled specimens by electrolytic etching with a 40% NaOH solution. In order to ascertain the nature of the brittleness the specimens were also tested at various other temperatures (Fig. 3).

Fig. 3. Impact bending tests on built-on metal at different temperatures: a - initial state; b - state at 475° brittleness

The data given confirm the fact that there is a difference in principle between the mechanism of the development of the 475-degree brittleness and the phenomena of cold flow and temper brittleness of low-alloy steels; 475-degree brittleness is detected at all test temperatures below 475°, while the processes governing the temper brittleness and sensitivity of ferrite steels to cold brittleness take place at higher temperatures. This difference should be particularly underscored since some authors identify 475-brittleness with temper brittleness [1].

In order to study the effect of subsequent heat treatment on 475-degree brittleness, after 1000 hour soaking at 475° the built-on metal was further heated for 3 hours at 540, 580, 650, 750 and 1000° followed by air cooling. Next, the specimens were put through impact bending tests at room temperature, the microhardness of the ferrite was determined and its microstructure investigated.

Results of the microhardness and impact bending tests (Fig. 4) show that the following 3 hour heating at 540, 580, and 650° causes a considerable increase in the impact toughness and a reduction in the microhardness of the ferrite in specimens which have been in the 475-degree brittleness state; but, neither the impact toughness nor the microhardness attain values corresponding to the states after welding.

After soaking at 750° the impact toughness is not increased. Soaking at 1000° totally removes 475-degree brittleness and leads to an increase in impact toughness and a corresponding reduction in microhardness above and below the initial value (see Fig. 4).

Since the brittleness is partially removed after heating for 3 hours, it would be logical to assume that further heating or briefer heating at 540 - 650° would completely eliminate it.

However, it can be seen from Fig. 5 that the impact toughness of specimens with 475-degree brittleness does not reach the initial value, no matter how long they are heated at 580° afterward; the maximum increase (55%) of the initial value is observed after 10 minutes heating at 580°; if the heating is increased to 6 hours, the impact toughness remains unchanged and then begins to decline sharply.

Metallographic study after subsequent heating for 3 hours at 540, 580 and 650° does not reveal any great change in the structure of the surface metal, compared with the brittle state. The greater etchability of the ferrite is the only thing that should be mentioned. When electrolytically etched in oxalic acid the ferrite areas, just as in the brittle state, turn a brown color; carbide formation or the precipitation of other excess phases is not observed at these temperatures.

Fig. 4. Effect of heat treatment on impact toughness and microhardness of ferrite in brittle specimens

Substantial changes in the structure of metals with 475-degree brittleness are detected after heating at 750° (Fig. 6a). In this case there is active formation of σ phase along the boundary zones of the ferrite areas. The remaining ferrite retains its ability to be stained brown by etching (as in the brittle state); its microhardness stays the same as after prolonged heating at 540, 580 and 650° (about 350 kg/cm²). Thus, the ferrite shows considerably less hardness than in the embrittled state, although it is higher than the initial value. The microhardness of the areas of precipitated σ phase is 700 - 850 kg/cm².

These transformations are not observed when the same metal is given the same heat treatment (750° for 3 hours) in the initial state. Here the σ phase is not formed and the ferrite areas decompose into ferrite and austenite (Fig. 6b).

The differences between the initial state of the built-on metal and 475-degree brittleness in the structural changes at 750° should be regarded as indirect evidence of the relationship between the 475-degree brittleness and formation of the σ phase.

At the same time we measured the magnetic saturation and coercive force of the built-on metal during prolonged