Brittle Fracture Resistance of Anti-Corrosive Cladding on Pressure Vessel

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ABSTRACT

The estimation of brittle fracture resistance of austenitic-ferritic anticorrosive cladding metal, produced by submerged arc welding with the use of strip electrodes of Cb-07X25H13 and Cb-08X19H10Г2Б types was made. The dependence of impact toughness an temperature both in as produced condition and after the exposure to a neutron fluence together with the temperature dependence of cladding metal static crack resistance were determined. The transition from ductile to brittle condition for cladding metal was found to be typical for a ferritic-perlitic steel.

INTRODUCTION

Most reactor-pressure vessels fabricated from 15X2MFA and 15X2HMFA steels are cladded on the inside by over-laying stainless steel to prevent from corrosion in a heat water (Balandin et al, 1984). The cladding metal fatigue strength is ignored when principal dimensions are determined to calculate pressure vessel strength. Yet, a convincing evidence of an increased brittle fracture resistance of 15X2MFA steel has been obtained in testing large-size bi-metallic specimens having a defect (a fatigue crack) through the austenitic cladding (Anikovsky et al, 1984). Therefore, the favourable effect of cladding is suggested (Gorynin et al, 1985) to be taken into consideration when calculating brittle fracture resistance. The use of this possibility to the maximum advantage depends to a large degree on how much resistant to brittle fracture the clad metal is. This point seems to be senseless with respect to the metal having an austenitic structure which is basically non-coldbrittle. However, recently information has appeared (Corwin et al, 1984) that double-layer cladding metal deposited with the use of austenitic welding materials (strip of 308 and 309 steels) reveals a ductile-to-brittle transition within room temperature down to -50°C which is typical for cold-brittle ferritic-perlitic steels. Moreover, the transition temperature of the materials mentioned above rises under the effect of neutron irradiation. In this connection it has become essential to check to what extent this property shows up in the cladding metal deposited by Soviet austenitic materials, and to find its reason as far as possible.

TEST MATERIALS AND EXPERIMENTAL PROCEDURE

In order to carry cut the scheduled investigations a 140 mm thick plate of 15X2MFA steel was commercially cladded with two layers using a welding strip of Cb-07X25H13 type (inner layer - one run) and of Cb-08X19H10Г2Б type (outer layer - two runs). The chemical composition is given in Table 1.

Table 1

Material	Element content, wt								
	C	Si	Mn	Cr	Ni	Nb	Cu	S	P
Cb-07X25H13	0.07	1.02	1.20	23.65	13.80	-	0.1	0.003	0.012
Cb-08X19H10Г2Б	0.04	0.66	1.48	18.40	9.28	0.94	0.1	0.004	0.014

The metal was heat treated to the pressure vessel standard conditions (665+10°C, 30 hours, air).
Mechanical properties of cladding metal were determined by static tensile test five diameter long specimens of 3 mm in diameter (see table 2).

Table 2

Site of sampling	+350°C				+20°C				-100°C			
	σ_y MPa	UTS MPa	δ %	ψ %	σ_y MPa	UTS MPa	δ %	ψ %	σ_y MPa	UTS MPa	δ %	ψ %
Inner layer	260	438	26	61	465	580	42	54	520	820	42	32
Outer layer	278	394	24	64	380	613	46	55	591	905	44	34

Dynamic and static bending tests of 10x10x55 mm specimens (with a sharp notch) were used to evaluate the brittle behaviour of the cladding overlay. The cross-section of specimens included both layers of the cladding. Small impact test specimens of 5x5x27.5 mm in size were prepared to evaluate individual properties of each cladding layer.
A notch in impact test specimens was made in all cases on the back side normal to the bead. In static bending tests the notch direction was varied so that in one case it was located in the same way as in impact bending test specimens, and in the other normal to the bead. In all the cases the notch direction coincided with that of axes of large columnar dendrites in the anti-corrosive cladding, i.e. the fracture of these specimens should occur in weaker bonds. In all triple-point static bending test specimens there was a fatigue crack 0.5 depth. The loading frequency and the number of loading cycles, as well as test equipment, measuring devices and test procedure, all met the GOST 25.506-85 requirements. The fracture toughness value K_{1J} was determined using a critical value of the J - integral J_{1C} in testing small-size specimens. Well known relationships were used

$$J_{1C}=\frac{2\cdot A}{h\cdot t}\ , \qquad K_{1J}=\sqrt{\frac{J_{1C}\cdot E}{1-\nu}}\ ,$$

where h, t - height and thickness of the net-section of specimens;
E, - elasticity modulus and Poisson coefficient;
A_o- specimen deformation energy by the moment of the crack initiation.

By impact strength tests standard specimens (the section of specimens comprised both layers of cladding) in the temperature range of -196 +20°C some of them were irradiated by neutrons $F=9\cdot 10^{23}$ neutr/m^2 and t_F= 270°C. For estimation of each layer properties small impact test specimens were made in size 5x5x27.5 mm, which were exposed to neutron fluence (T_F= 210-250°C) $F=1.3\cdot 10^{24}$neutr/m^2. In order to find factors responsible for the brittleness of the cladding metal the microstructure of the latter was investigated under optical and electron microscopes.

EXPERIMENTAL RESULTS AND DISCUSSION

Triple-point bending tests showed a smooth decrease in fracture toughness of the austenitic cladding overlay with the drop from room temperature down to -196°C. The experimental data in Fig.1 a are given in comparison with the bottom envelope of the temperature dependence of 15X2MFA steel brittle fracture which as is shown (Gorynin et al, 1988) can be presented as $K_{1C}= 50\cdot\exp(0.032T)+ 30$. It is evident that the $K_{1C}= f(T)$ curve and the lowest J_{1C} values for the cladding metal approximate to those for cold-brittle ferritic-perlitic steel. One can see from the data obtained that the adapted different orientation of notches in specimens has actually no effect on brittle fracture obtained using the J-integral method.

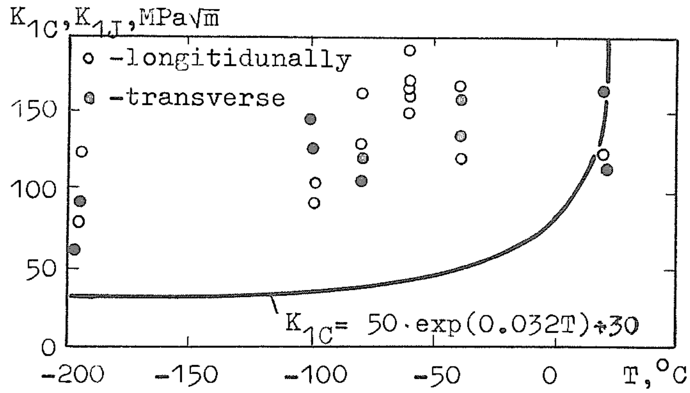

Fig.1.Cladding fracture toughness by static loading.

Impact bending test results for both size types are given in Fig.2 which shows that ductile-brittle fracture in materials tested occurs in a narrow temperature range. Transition temperature measured to suit 40 J/cm² in testing specimens prepared from both cladding layers is -40°C, inner and outer metal layers having -30 and -50°C, respectively.

After exposure to neutron fluence at VVER-440 reactor work temperature (270+10°C) the impact strength temperature dependence shift to a higher temperature region accounts for 50°C, and critical brittle T = -10°C. At lower irradiation temperature (210-250°C) and 1.5 times as much neutron fluence a critical temperature shift for a outer cladding properly contacted with a heat tranfer agent, is equal to 50°, and for an inner cladding -90°. However, in this case by the action of neutron fluence complying with 30-years of reactor service, the critical brittle temperature of the cladding material produced by Cb-07X25H13 welding electrode, amounts to 60°, which is lower, than for a base metal.

Optical microscopic examinations have shown that the structure of cladding metal is typical for cast austenitic steel, some irregular shape δ-ferrite areas surrounded by carbide precipitations being observed against the background of austenitic structure. Electron microscope examination has provided support for the fact that the larger part of the microstructure consists of the austenite of high density dislocations and a great number of fine-dispersed precipitations. They were identified to be NbC type carbides. Austenitic grain boundaries abound in larger NbC carbide precipitations. Elongated areas of several micron in size and of an irregular shape form the rest of the structure. These areas are mainly arranged along the grain boundaries. Basically they are δ-ferrite areas with the dislocation density of 1 to 2 order of magnitude lower than in the austenite. One-by-one or chain like precipitations of special $Me_{23}C_6$ and NbC carbides dispose along the austete-ferrite interface.

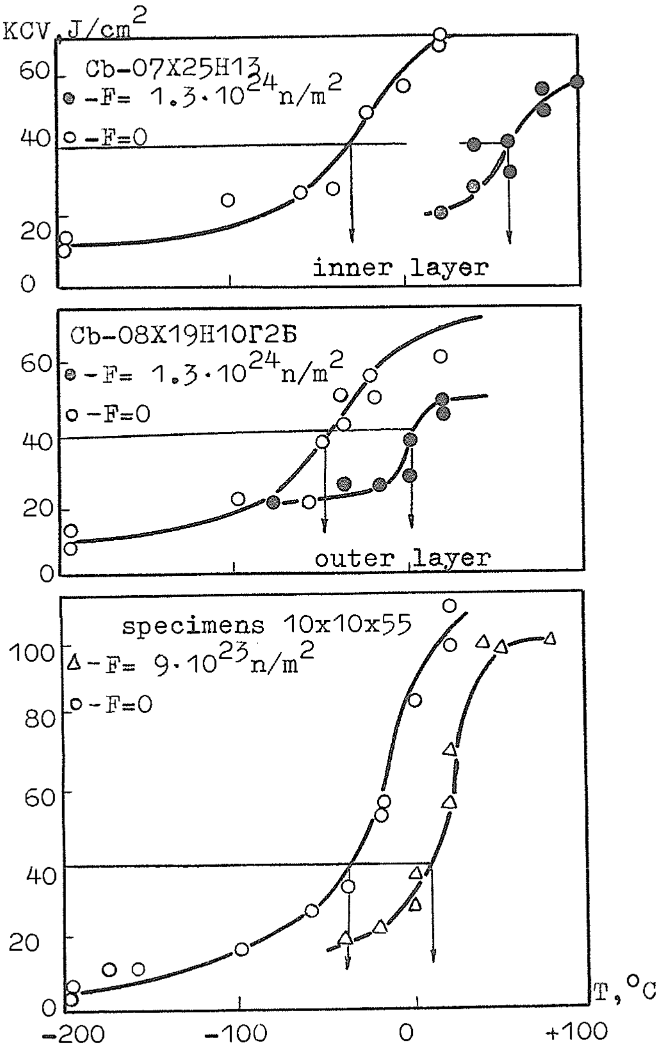

Fig.2.Cladding impact strength of 10x10x55mm and 5x5x27.5mm specimens.

However, not all the micro-areas prove to be δ-ferrite areas. Some of them, based on the results of the microdiffraction analysis, are identified as the σ-phase of the Fe-Cr system. In some cases these areas have a complex structure and are formed of δ-ferrite and σ-phase. The latter bears witness to the fact that a σ-phase of the similar morphology can form as a result of a partial decomposition of δ-ferrite. The σ-phase precipitated has an equaxial or slightly oval shape of 1 to 2 micron in size.

The results of the experiments performed confirm that the metal of an anti-corrosive cladding overlay made with austenitic materials is prone to cold-brittleness typical for ferritic-perlitic steel. The microstructural analysis has made it possible to reveal interdendritic interlayers of cold-brittle δ-ferrite forming a kind of a met (framework) along the boundaries of primary austenitic crystalline grains. The fractographic examination has identified separate facets of cleavage between areas of grain boundary fracture.

The combined experimental data allow to suppose that when the test temperature falls the interlayers of the ferritic phase show brittle failure which seems to be assisted by the origination of internal stresses governed by more than one and a half difference in the linear expansion factors of austenite and ferrite. The cracks developed are likely to be uncapable to cross the austenitic grains and detour on the brittle constituent. As a conseguence, the fracture surface has an appearance which is typical for intercrystalline fracture. When ferritic interlayers do not connect with each other some ductile addtear zones can be observed.

CONCLUSIONS

1. Under certain conditions cladding metal on reactor case tends to brittle fracture at the expence of δ-ferrite areas available in austenite.
2. Cladding metal fracture toughness in the whole temperature range of $-196...20^\circ$C is higher than would be in the case of a heat-resistant ferritic-perlitic steel.
3. Cladding metal in as-produced condition has a transition temperature of -40°C which is determined from the impact strength value of 40 J/cm^2.
4. The transition temperature of specimens irradiated at high neutron fluence of $1\ 10^{24}$ n/m^2 ($E \geqslant 0.5$ Mev) is shifted to the higher temperature range (~ by 50°).

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