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Deformation and fracture of the metal of a dissimilar steels weld under conditions of complex stress state and elevated temperatures

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ABSTRACT

The paper presents the results of the experimental study into the effect of temperature and type of loading on the load-carrying capacity of dissimilar metals welds of austenitic steel 10Kh18N10T-VD and pearlitic steel 10GN2MFA-III which allow to assess the influence of the above service factors upon strength characteristics of the material used in a highly loaded structure of the steam generator collector and to assess the level of permissible limit stresses (both thermal and mechanical) in the metal of a dissimilar steels weld.

EXPERIMENTAL PROCEDURE, RESULTS AND THEIR DISCUSSION

The present experimental study is devoted to the investigation into the regularities of deformation and fracture of the weld metal in a welded joint of steel 08Kh18N10T-VD and steel 10GN2MFA-III at a single load application under conditions of complex stress state over the temperature range corresponding to service conditions of steam generators of type PGV-1000U (20...320°C). The tests were conducted with the use of two types of specimens: plane specimens were tested under conditions of uniaxial tension whereas tubular ones in uniaxial and biaxial tension.

Plane specimens were cut out of a shell consisting of the austenitic and pearlitic steels welded together. The specimens were cut out of the shell layers with different weld heights (Fig. 1). Here, the weld metal length along the specimen working section varied somewhat from layer to layer. It was minimal for specimens cut out of the first layer of the shell weld and maximal for specimens cut out of the third layer of the weld.

The tests were carried out on a conventional "Baldwin" - type tearing machine using the specimens shown in Fig. 2.

A series of investigations performed has shown that depending on the location of the weld metal layer in its height, the stresses, which correspond to failure, differ somewhat at the same temperature which is due to different strength characteristics of the welded steels and to different sizes of the weld which is within the specimen working section. The observed regularity is characteristic of the whole temperature range under study as evidenced by the results presented in Table 1.

The character of the variation of the weld metal strength properties depending on the layer in the weld height can be followed in Fig. 3. As can be seen, the strength characteristics in the middle layer of the weld are somewhat higher as compared to the outer layers.

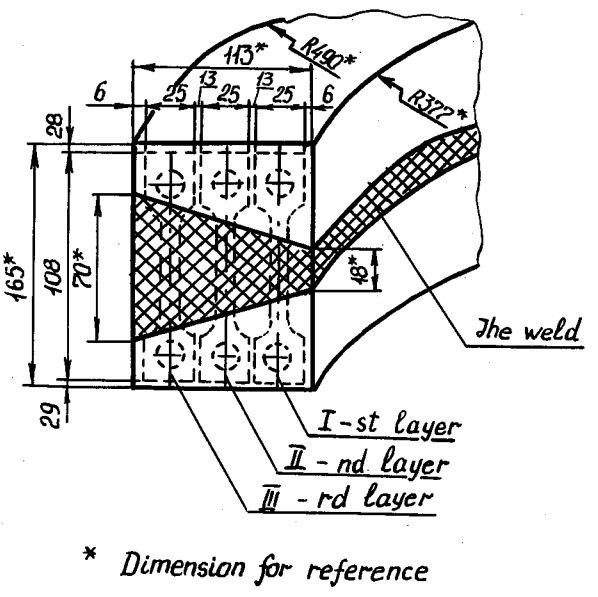

Fig. 1. A scheme of cutting the shell from a dissimilar metals weld of steels 08Kh18N10T-VD and 10GN2MFA-III into billets for plane specimens.

Table 1. Strength and plasticity characteristics of metal in a dissimilar metals weld of steel 08Kh18N10T-VD (steel A) and steel 10GN2MFA-III (steel B) in uniaxial tension

Number of the weld layer out of which the specimens was cut	L mm	δ mm	F mm	t, °C	$\sigma_{0.2}$ MPa	σ_u MPa	ε_b %	N Kg	Failure location
I	7.04	4.03	28.49	20	384.0	426.1	11.4	1640	near-weld zone on the side of steel A
I	6.86	4.025	27.61	285	346.7	405.6	4.18	1120	
I	6.73	4.03	27.12	320	328.0	389	3.75	1055	
II	7.1	4.01	28.11	20	473.0	606.5	7.97	1705	weld metal on the side of steel B
II	6.74	4.015	27.06	285	372.5	465.6	4.06	1260	
II	6.55	4.015	26.3	320	385.4	43.35	3.19	1140	
III	7.02	4.015	28.14	20	469.0	541.8	4.56	1525	weld metal on the side of steel B
III	7.04	3.59	25.27	285	344.4	379.9	1.81	960	
III	6.62	4.015	26.58	320	328.0	423.2	4.19	1125	

Note that the variation of the strength characteristics depending on the size of the zone on the specimen working surface covered by the weld metal is nonlinear.

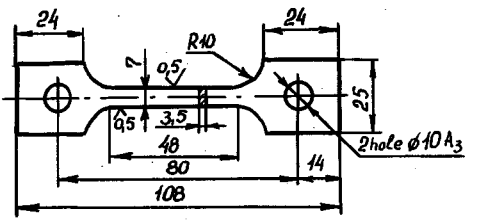

Fig. 2. Plane specimen for tensile tests.

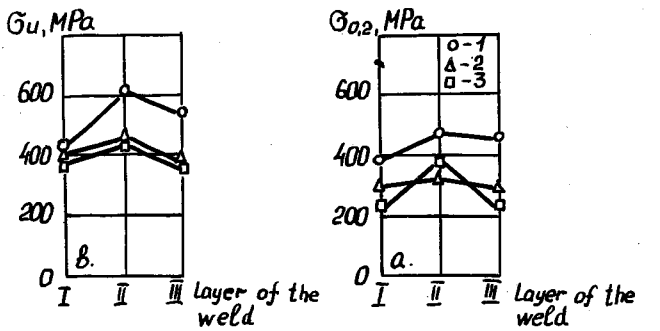

Fig. 3. The character of yield stress (a) and ultimate strength (b) variation in the metal of the dissimilar steels weld for certain layers of the shell (billet): 1 - Ist layer, 2 - IInd layer, 3 - IIIrd layer.

The results presented in Fig. 4 reflect the peculiarities of changes in deformation characteristics of the weld metal depending on the layer in the weld height from which the specimen was cut out for all the temperature levels realized.

An increase in the test temperature lowers somewhat the weld metal strength and deformation characteristics for all the layers througthout the dissimilar steels weld height (Fig. 5).

It should be noted that the tests performed on plane weld metal specimens which were cut out of different locations in the shell wall thickness from each of the weld layers revealed the isotropy of strength and deformation characteristics of this metal within the same layer.

The results of experimental investigations into the load carrying capacity and deformation properties of the metal of a weld of dissimilar steels 08Kh18N10T-VD and 10GN2MFA-III under different types of loading at room and elevated temperatures are given below.

To conduct experimental investigations under conditions of a complex stress state, tubular specimens from the dissimilar steels weld metal were used. The specimen billets were cut out of the metal layers with different height of the weld metal. The tests were carried out on the CHT-8-type machine described together with the procedure elsewhere [1] in uniaxial tension $(K = \sigma_z/\sigma_\theta = \infty)$ and in nonuniform biaxial tension, i.e. the specimen was loaded by internal pressure $(K = \sigma_z/\sigma_\theta = 0.5)$. For both types of loading, the tests were carried out on specimens cut out of layer II of the shell at temperatures 20, 285 and 320°C. In the course of the experiments, the loading rate was kept constant.

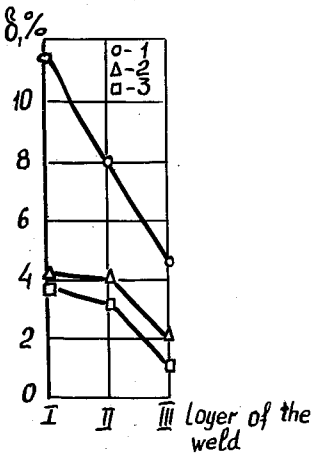

Fig. 4. The dependence of the weld metal elongation upon the location of the layer of which the specimen was cut out at different temperatures: 1 = 20°C, 2 = 285°C, 3 = 320°C.

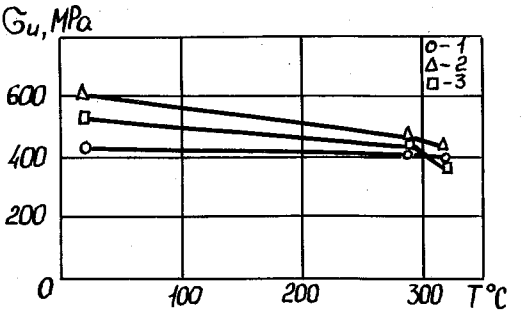

Fig. 5. The influence of temperature on the ultimate strength of the weld metal determined on plane specimens cut out of different layers of the shell (billet):
1 - Ist layer, 2 -IInd layer, 3 - IIIrd layer.

When processing the test results obtained for tubular specimens under different types of loading, the stress and strain intensities were used as equivalent stresses and strains. To calculate the stress and strain intensities the known relationships were employed.

It should be noted that such an approach to the evaluation of deformation and strength properties of the dissimilar weld metal is, to a certain extent, conventional and approximate.

Table 2. Strength characteristics of a dissimilar steels at weld studied at different types of loading and temperatures.

T, °C	Type of loading	Limiting loads		σ_i	Character of fracture
		σ_z, MPa	σ_θ, MPa	MPa	
20	Uniaxial tension $K = \sigma_z/\sigma_\theta = \infty$	856.8	-	856.0	Ductile failure
	Internal pressure $K = \sigma_z/\sigma_\theta = 0.5$	343.0 400.0	686.0 799.0	594.0 692.0	Ductile failure
285	Uniaxial tension $K = \sigma_z/\sigma_\theta = \infty$	506.0	-	513.1	Ductile failure
	Internal pressure $K = \sigma_z/\sigma_\theta = 0.5$	251.0	502.0	435.0	Ductile failure
320	Uniaxial tension $K = \sigma_z/\sigma_\theta = \infty$	513.0	-	506.0	Ductile failure
	Internal pressure $K = \sigma_z/\sigma_\theta = 0.5$	207.0	413.0	358.0	Ductile failure

Table 3. Plasticity characteristics of a dissimilar steels weld studied at different types of loading and temperatures.

T, °C	Type of loading	Limiting strains			Location of failure
		ε_z, %	ε_θ, %	ε_i, %	
20	Uniaxial tension $K = \sigma_z/\sigma_\theta = \infty$	2.9	0.827	2.87	across the weld close to steel 10GN2MFA-III
	Internal pressure $K = \sigma_z/\sigma_\theta = 0.5$	0.089 0.063	2.08 0.608	2.35 0.614	across the weld in the centre across the weld close to steel 08Kh18N10T
285	Uniaxial tension $K = \sigma_z/\sigma_\theta = \infty$	0.739	0.21	0.806	within steel 08Kh18N10T
	Internal pressure $K = \sigma_z/\sigma_\theta = 0.5$	0.089	0.463	0.51	across the weld in the center
320	Uniaxial tension $K = \sigma_z/\sigma_\theta = \infty$	0.808	0.414	0.721	within steel 08Kh18N10N
	Internal pressure $K = \sigma_z/\sigma_\theta = 0.5$	0.037	0.736	0.51	across the weld in the centre

Nevertheless, such choice of characteristics makes it possible to judge the load-carrying capacity and deformation properties of a dissimilar steels weld under different types of loading and to study the regularities of variation of those characteristics depending on the test temperature and type of loading.

The evaluation of deformation properties of the weld metal was made from uniform plastic strains corresponding to fracture without consideration of local strains in the specimen neck or in the zone of buckling.

The experimental data on the mode of fracture and the limiting values of strength and plasticity characteristics for the realized types of loading and temperatures are listed in Tables 2 and 3. Those data indicate that an increase in the temperature from 20°C to 320°C results in a reduction of the strength and deformation properties of the weld metal in both uniaxial and biaxial tension. A graphic interpretation of those results is given in Figs 6 and 7 where temperature dependences of fracture stresses and corresponding limiting strains in uniaxial tension and under loading by internal pressure (nonuniform biaxial tension) are presented. As is seen, the reduction in strength characteristics of the weld metal in uniaxial tension over the temperature range from 20 to 285°C proceeds more intensively than in biaxial tension. At the same time, in the temperature range from 285 to 320 °C a decrease in the maximum stress value, which corresponds to fracture, proceeds more intensively under conditions of nonuniform biaxial tension as against a similar process in uniaxial tension.

The analysis of the test results presented for tubular specimens has shown that strength and deformation properties of the weld metal depend on the type of loading. In nonuniform biaxial tension in the temperature range studied, plastic and strength properties reduce as compared to those in uniaxial tension. In going from uniaxial to nonuniform biaxial tension, strength characteristics of the weld metal vary less essentially depending

on the type of loading. Basing on the results of a series of investigations performed, the analysis has been made of the fracture character of the specimens whose working section was made of the metal of the dissimilar steels weld. As a whole, for the types of loading and temperatures under study, the fracture was ductile. Characteristic features of this process for different types of loading, as well as for a number of other materials [2] were such that in uniaxial tension fracture occurred across the sections perpendicular to the specimen longitudinal axis, whereas in biaxial tension ($K = 0.5$) the crack developed along the generatrix of the cylinder of the specimen working section. In this case, the main crack for the majority of specimens tested at all the realized temperature levels and types of loading propagated in the metal of the dissimilar steels weld rather than in one of the two welded steels.

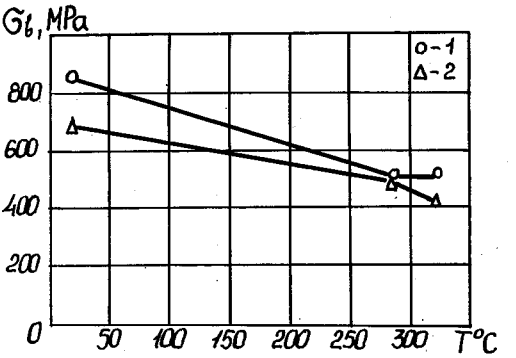

Fig. 6. The influence of temperature on the maximum stress which corresponds to fracture of the weld metal under different types of loading: 1 - uniaxial tension, 2- nonuniform biaxial tension (internal pressure).

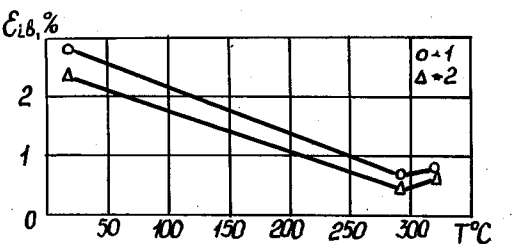

Fig. 7. The influence of temperature on the strain intensity value of the dissimilar steels weld metal under different types of loading. The notations are the same as in Fig. 6.

The analysis of the specimen fracture surfaces has shown that in all the cases this process proceeded along the planes of maximum tangential stresses.

CONCLUSIONS

1. On the basis of the investigation into the uniformity of strength and deformation characteristics over the height of a dissimilar steels weld (austenitic 08Kh18N10T-VD and pearlitic 10GN2MFA-III steels) under conditions of uniaxial tension, it has been found that

- the magnitudes of strength characteristics of the dissimilar steels weld metal increase somewhat in the middle part throughout the weld height as compared to those of the metal near the weld edges;
- the plasticity of the weld metal increases over its height from the weld top to the base, i.e. from its wider upper part to the narrower lower part (the welded joint is V-shaped);
- a rise in the test temperature to 320°C lowers the strength and deformation characteristics of the weld metal.

2. The study of strength and plasticity characteristics of the dissimilar steels weld at different types of loading in the service temperature range of NPP steam generators revealed that:

- strength and plasticity of the weld metal depend on both the temperature and the type of loading. In biaxial tension, a 15 to 20 % reduction of the maximum stresses corresponding to fracture is observed, whereas the plasticity characteristics expressed in terms of strain intensities ε_i decrease by 20 to 30 % as compared to those of the weld metal in uniaxial tension. The above circumstance should be taken into account when using the welded joint studied in real structures; an increase in the test temperature to 320°C results in a decrease in strength and plasticity characteristics of the weld metal. In the temperature range from 20 to 285°C the intensity of such reduction in the above characteristics is higher than in the range from 285 to 320°C.

REFERENCES

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2. Pisarenko G.S. & A.A. Lebedev 1976. *Deformation and strength of materials at complex stress state.* Naukova Dumka, Kiev (in Russian)