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RESEARCHES ON THE INFLUENCE OF MAKING TECHNOLOGY OF STEELS USED FOR NAVAL STRUCTURES CONSTRUCTION ON CORROSIVE ENVIRONMENT FATIGUE STRENGH

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ABSTRACT

This papers presents experimental results concerning the influence of the corrosive environment (water solution with 3% NaCl) on the fatigue resistance of a ship building steel grade for different technological processes (rolled or cast) and for different design (welded or non-welded).

1. INTRODUCTION

The fracture by fatigue in corrosive environment is an accumulating step-by-step process of damaging characteristic under the simultaneous action of cyclic loading and the corrosive environment: the results are a change the material characteristics and a specific initiation and generation of the cracks. All the materials based on iron, aluminum, titan, copper and even other ferrous or non-ferrous materials, may have this particular process of damaging. This damaging process characterizes the drilling tubes, compressor blades and reactive engines, ship propeller, oil piping system, etc.

The damaging process in corrosive environment has another characteristic: the absence of any correlation between the mechanical characteristics for static loading and those for the cyclic one. The processes of the adsorption, hydrogenating, anodic solving, the physical and electro-chemical properties of the metallic material and the loading conditions (load, temperature, etc) influence the fatigue in corrosive environment.

Based on the specialists information and on the authors' results, Petrov, Stepurenko, (1982), Palaghian, (1997), it seems obvious that the fatigue resistance in corrosive environment is affected by the parameters of the superficial layer (stress state, hardness, chemical composition, structure, purity). Other influencing parameters are typical for the corrosive environment: the nature of the solution, the anions concentration and the concentration of the atomic hydrogen, the concentration of the corrosion inhibiting substances. The loading conditions (the magnitude and the character of the load, the loading frequency, the shape and the dimensions of the samples) also affect the fatigue resistance in corrosive environment.

As regards the technological aspects of D 32 ship building steel, there are only few references in engineering literature of half-manufactured obtaining technology and joining influence on the fatigue resistance, both in air and in corrosive environment, Tanaka, Kinoshita, Nakayama, (1995).

2. MATERIALS TESTED

This paper studies the following technological and joining aspects on the fatigue resistance, both in air and in corrosive environment (3% NaCl solution):

I) The iron plate half-manufactured obtaining technology:
  a) rolling by ingot casting half-manufactured.
  b) rolling by continuous casting half-manufactured;

II) Iron plate half-manufactured thickness

III) Rolling direction

IV) The steel casting technology

V) The welding technology
  a) head-to-head;
  b) longitudinal seam welding;
  c) spot welding;

VI) Bimetallic joints bonded with adhesive.

Table 1 presents the samples cutting methodology used to study the influence of factors I and II on fatigue resistance, both in air and in corrosive environment.

The samples were cut from iron plate of 10 mm thickness. For welding electrodes, having the composition: *C = max 0,12%; Mn = max 0,7%; Si = max 0,8%; Cr = max 18%; Ni = max (8÷10)%; S = max 0,018%; P = max 0,03%; Ti = max (0,5÷1)%* were used.

The bimetallic joints were made from D32 steel plated with stainless steel. The plating sheet thickness was 2 mm, the base material thickness was 7,5 mm and the adhesive layer thickness 0,5 mm. Three phenollic adhesive types with elasticity modulus 450 MPa, 900 MPa and, respectively, 1800 MPa were used.

Table 1 The type of samples

Sample code	Technology	Ingot zone	Cutting-off direction versus rolling direction	Thickness [mm]
1	ingot	top	longitudinal	20
2	ingot	top	longitudinal	40
3	ingot	bottom	longitudinal	40
4	continuous casting	-	longitudinal	20
5	continuous casting	-	longitudinal	40
6	continuous casting	-	longitudinal	20

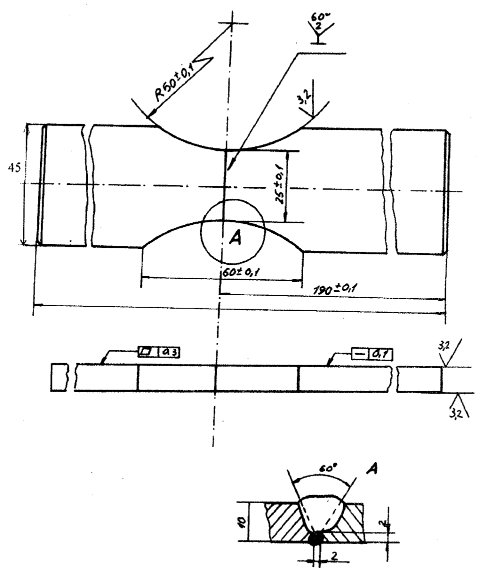
Figure 1a, b and 5 present the shape and dimension of welded, non-welded, respectively, with seam and spot welding samples, respectively.

The chemical composition of D32 steel is given in table 2.

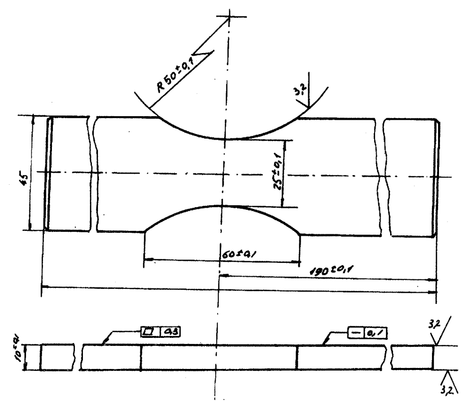
Table 2. Chemical composition of the steel grade D 32 [%]

C	Mn	Si	Cu	Al	Cr	Ni	Mo
max. 0.18	0.90	0.10	0.35	0.02	0.20	0.20…0.40	0.08

The fatigue tests, both in air and corrosive environment, were carried out on a plane bending machine (figure 2), in symmetrical alternating cycles (R=-1). The cycles basic number for air tests was 10^7 cycles and for corrosive environment tests was $3x10^7$ cycles.



a)



b)

Figure 1
Type of samples
a) welded sample b) non-welded sample

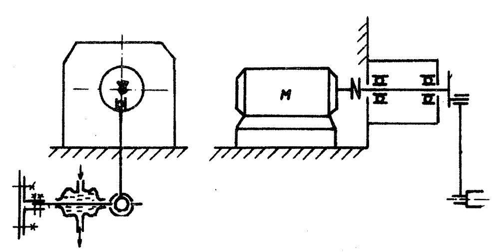


Figure 2
The fatigue testing machine for corrosive environment

3. EXPERIMENTAL RESULTS AND DISCUSSION

The results from the testing samples are presented in the following figures:

- figure 3: the experimental results obtained for air, by two different technologies: rolling on ingot or rolling a continuous casting slab;
- figure 4: the experimental results obtained in corrosive environment by two different technologies: rolling on ingot or rolling a continuous casting slab;
- figure 5: fatigue curves in air and corrosive environment for samples made of D 32 steel from rolled sheet, with longitudinal welded seam and with spots deposited on the sample surface;

-figure 6: a diagram comparing the experimental results for welded samples made of steel grade D 32 to those obtained for non-welded samples made of rolled sheet;

-figure 7: a diagram comparing the test results of head-to-head welded samples to those of cast steel samples;

- figure 8: fatigue limit in air and corrosive environment for joints bonded with adhesives.

The experiments pointed out that in air, figure 3, the sample cut-off from sheets with 20-mm thickness had a greater fatigue resistance than that of the samples obtained by using 40-mm thickness sheets. This evidently underlines the influence of the deformation degree in rolling. The magnitude of the reducing degree leads to the structure finishing and thus to the increase in the fatigue resistance.

The experimental results indicate that the samples obtained from the ingot bottom have higher resistance than that of the samples obtained from the ingot top due to a more homogenous structure and higher purity characterizing this zone of the ingot. The ingot top is characterized by higher concentration of impurities that will become sources of micro-cracks.

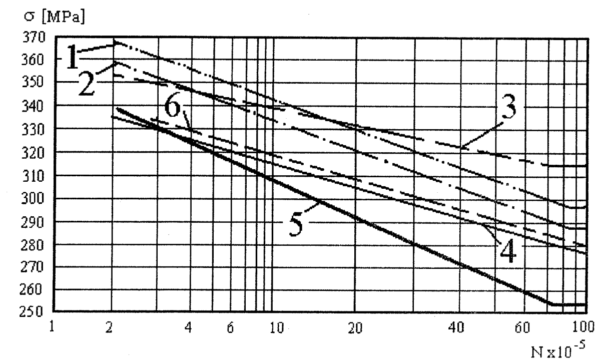


Figure 3

The experimental results in air

1-ingot top, longitudinal, 20 mm; 2-ingot top, longitudinal, 40 mm; 3-ingot bottom, longitudinal, 40 mm; 4-continuous cast, longitudinal, 20 mm; 5-continuous cast, longitudinal, 40 mm; 6-continuous cast, transversal, 20 mm.

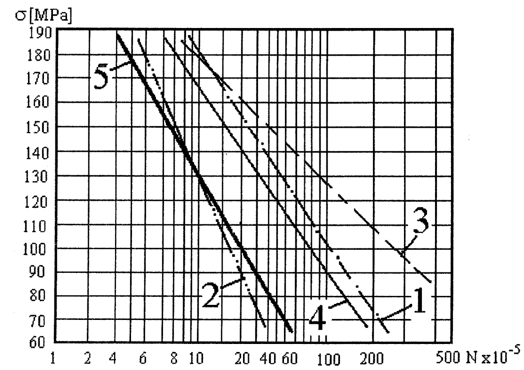


Figure 4

The experimental results in corrosive environment

1-ingot top, 20 mm; 2-ingot top, 40 mm; 3-ingot bottom, 40 mm; 4-continuous cast, 20 mm; 5-continuous cast, 40 mm.

From the output data it was not possible to establish the influence of the rolling direction.

The decreasing deformation degree for the continuously cast steel induces the fatigue limit to be smaller than that of the sample made of cast ingots.

A high fatigue resistance in a corrosive environment is ensured by accurate technology avoiding the impurities, the inclusions and the segregation processes. If the technology could meet these conditions, it would be avoided the initiation of the stress concentrators, the formation of galvanic micro-cells (due to the composition) and cells featuring elastic distortion, either by reducing the cathodic activity or by reducing the anodic one.

Thus, for the ingot cast steel the experiments (figure 4) reveal that, the ingot zone, the sample were cut-off from has the greatest influence on the conventional fatigue resistance in corrosive environment. The samples obtained from the ingot bottom having a higher resistance, comparatively with that cut-off from the ingot top.

Both in continuous casting and ingot casting cases, the samples cut from thinner iron plates have the corrosive environment fatigue resistance higher than those cut from thicker ones. The explanation of this is that the decrease in the deformation leads to lower chemical and structural non-homogeneous.

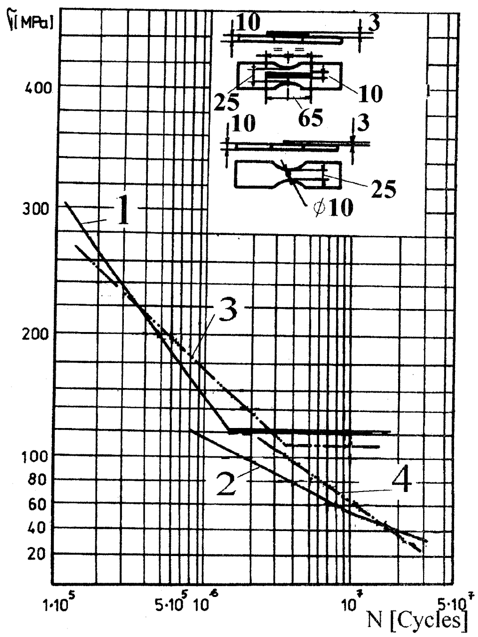


Figure 5
Fatigue curves in air and in corrosive environment for welded samples
1- samples with longitudinal welded seam, tested in air; 2- samples with longitudinal welded seam, tested in corrosive environment (water solution with 3 % NaCl); 3-samples with welded spot, tested in air; 4- samples with welded spot, tested in corrosive environment

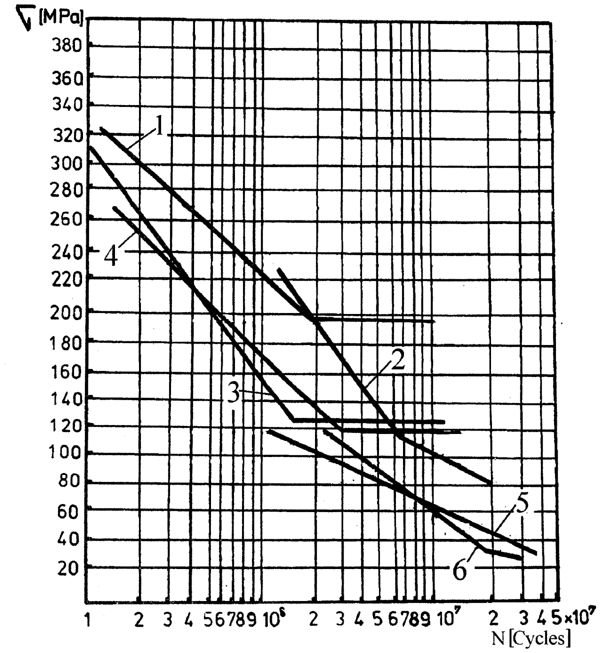


Figure 6
A diagram comparing the experimental results for welded and rolled samples
1-rolled samples tested in air, 2- rolled samples tested corrosive environment; 3-samples with longitudinal welded seam, tested in air;
4- samples with welded spot, tested in air;
5- samples with longitudinal welded seam, tested corrosive environment; 6- samples with welded spot, tested in corrosive environment.

With respect to the seam and dot welding (figure 5), it is remarkable that the values of fatigue limits, Sonsinio, (1995), in air and corrosive environments, are comparable. Both the intense strain concentration and the local structure modification lead to decreasing of corrosive environment fatigue. In welding deposition case, a casting structure is obtained, less homogenous than that of the base material. This makes (figure 6) the corrosive environment fatigue of samples with deposited material be smaller than that of smooth rolling samples.

Comparing the test results from the head-to-head samples with those of casting D32 steel and those of iron plate rolled steel (figure 7, table 3), emphasizes that their air fatigue resistance is comparable. The cast steel samples have greater sensitivity at variable stresses.

In corrosive environment it should be noted head welding samples are greater that that of rolled samples. Higher inter-crystalline corrosion resistance of titanium oxide, formed in metallic smelting due to used electrode composition, explains this fact. Also, the longitudinal welding seam processing lead to decrease in the strain concentration effect.

Table 3. Experimental results for fatigue tests

Environment	Fatigue limit [MPa]	
Steel	Air basic number 10^7	Water solution with 3% NaCl basic number $3x10^7$
D 32 non-welded, rolled	190	65…70
D 32 head-to-head welded	200	110
D 32 with longitudinal welded seam	120	32
D 32 with welded dot	110	28
D 32 cast steel	190	70

The experimental results further allow to establish the stress concentration coefficient and the influence of the corrosive environment on the fatigue resistance for the steel grade D 32. This may be defined:

$$K_\sigma = \frac{\sigma_{-1}}{\sigma_{-1k}} \;;\; \gamma_\sigma = \frac{\sigma_{-1}}{\sigma_{-1c}} \;;\; K_\tau = \frac{\tau_{-1}}{\tau_{-1k}} \;;\; \gamma_\tau = \frac{\tau_{-1}}{\tau_{-1c}} \;; \tag{1}$$

where K_σ, K_τ are the stress concentration factors; σ_{-1}, τ_{-1} the fatigue limits in symmetrical alternate cycle for the samples without concentrators; σ_{-1k}, τ_{-1k} the fatigue resistance of samples with concentrators; γ_σ, γ_τ factors reflecting the surface quality and corrosive environment influence; σ_{-1c}, τ_{-1c} the conventional fatigue limits in symmetrical alternate cycles of smooth samples tested in corrosive environment, Teodorescu, Mocanu, Buga, (1972), Zaitzev, Aronson, (1975), Heywood, (1962).

$$c_\sigma = \frac{\sigma_{-1}}{\frac{K_\sigma \sigma_v}{\varepsilon_\sigma \gamma_\sigma} + \frac{\sigma_{-1}}{\sigma_r}\sigma_m} \;;\; c_\tau = \frac{\tau_{-1}}{\frac{K_\tau \tau_v}{\varepsilon_\tau \gamma_\tau} + \frac{\tau_{-1}}{\tau_r}\tau_m} \tag{2}$$

where ε_σ, ε_τ are the dimensional factors; σ_r, τ_r the breaking limits in stretch and, respectively, in torsion; σ_m, τ_m the mean values of the stress cycle; σ_v, τ_v the stress cycle amplitude.

If in the same point both perpendicular and tangent variable stresses are acting, the safety coefficient must be calculated by the following relation:

$$c = \frac{c_\sigma c_\tau}{\sqrt{c_\sigma^2 + c_\tau^2}} \tag{3}$$

From the fatigue tests in corrosive environment for bimetallic bonded samples the durability curves can be plotted. Similar to the tests made in normal air, Xu, Crocombe, Smith, (1997), either a displacement of the adhesive or a cracking by corrosive fatigue of the basic material was developed. As there was expected, the durability curve of the basic material (curve 4 in figure 8) have a totally descendent tendency characteristic for such tests with cyclic loading.

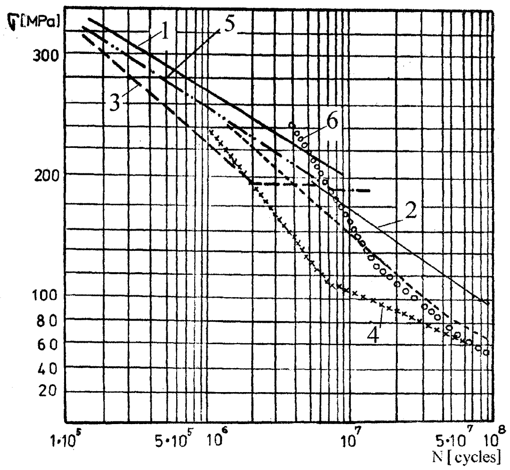


Figure 7

A diagram comparing the test results obtained for head-to-head welded samples to those for cast steel samples

1- steel D 32; head-to-head welded samples tested in air; 2- steel D 32; head-to-head welded samples tested in corrosive environment; 3- steel D 32; samples cut from rolled sheet tested in air;
4- steel D 32; samples cut from rolled sheet tested in corrosive environment; 5- D 32 cast steel; samples tested in air; 6- D 32 cast steel; samples tested in corrosive environment.

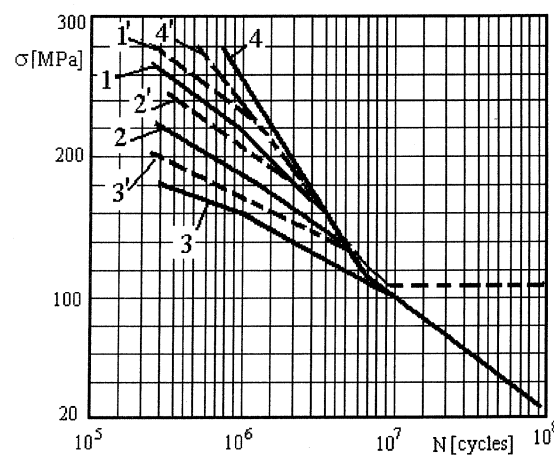


Figure 8

Fatigue limit in air and corrosive environment for adhesives bonded joints.

1,1'- adhesive A1, corrosive environment and air;
2,2'- adhesive A2, corrosive environment and air;
3,3'- adhesive A3, corrosive environment and air;
4,4'- basic material, corrosive environment and air;

The influence of the corrosive environment on the adhesive makes the durability curve have a broken zone, the detaching of the adhesive being performed at lower stresses and the experimental results were spread under a wider interval than those obtained in air. There still exists the same influence of the elasticity modulus on the fatigue limit. The adhesive having a higher modulus detaches itself at higher stress than that having a lower elasticity modulus (curves 1, 2 and 3 for the adhesives A1, A2 and A3, respectively).

The constituents of the corrosive environment influence bonded joints obtained by effect of mechanical adhesion. These, both as atoms and ions located themselves on the top of the micro-pores and of the initiating micro-cracks. This phenomenon destroys the crystalline lattice of the metal and the chemical activation also influencing the characteristics of the adhesive.

At the first signs of adhesive detaching the electrode potential features, Palaghian, Birsan, (1997), a significant rise tending to the value characterizing the basic material. This significant variation of the electrode potential for a certain stress level depends on the adhesive resistance to be detached. Thus the variation of electrode potential will give information on the behavior of actual joints during their exploitation, if this parameter is recorded.

4. CONCLUSIONS

The experimental researches on fatigue resistance in air and corrosive environment of the ship building steel D32, obtained by various technologies, point out to the following:

- The steel purity has greater influence on fatigue resistance, both in air and in corrosive environment. Foot ingot samples has the highest corrosive environment resistance. This is due to impurities migration, during the solidification time, to the ingot head area.
- With half-manufactured technologies, the rolling decrease of thickness leads to higher fatigue resistance in both environments.
- In welding joints, using an electrode of a suitable composition may lead to higher fatigue resistance in corrosive environment comparing with non-welded samples. This is due to some chemical structures with avoid the inter-crystalline corrosion danger.

The damage of bonded joints, subjected to variable stresses, both in air and in corrosive environment, is due to the adhesive layer shearing. The higher adhesive modulus of elasticity, the faster the detaching The corrosive environment is favorable to this phenomenon.

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