METHODOLOGY AND EQUIPMENT FOR RESEARCHING CORROSION CRACKING PROCESSES IN CASTING ALLOYS

Maria Krasteva

University of Chemical Technology and Metallurgy
8 Kliment Ohridski Blvd., Sofia 1797, Bulgaria
E-mail: mariqkrasteva@uctm.edu

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ABSTRACT

Corrosion cracking is the destruction of metal under static stresses and an aggressive environment. Corrosion fatigue is destruction of the metals and the alloys under the impact of cyclic mechanical pressure and aggressive environment simultaneously.

Stress corrosion is the least studied and systematized in terms of literature data on the impact of various aggressive environment (type, temperature, and concentration), composition and structure of the material, mode of heat treatment, method of obtaining and cleaning the casting, methodology for determination of corrosion under stress, as well as equipment for carrying out similar studies. The purpose of this paper is to present the methodology and equipment developed for corrosion cracking testing of cast alloys.

Keywords: stress corrosion, corrosion cracking, u-figurativeness test specimen, casting alloys.

INTRODUCTION

In corrosion cracking, parts and structures fail because of the surface cracking initiation and the subsequent growth of cracks into the material, which causes their instantaneous failure, which in turn determines the durability of metals and metal structures [1].

In the heat treatment and welding of workpieces, the potential for corrosion cracking depends on the phase composition and structural transformations taking place in the steel [2].

The potential of metals, and in particular steels, to corrosion cracking depends significantly on the composition of the environment (medium) in which the workpieces and structures are operated. As temperature and the electrolyte concentration increase, the aggressiveness usually increases as well.

There are no uniform theories and methodologies in literature for determining stress corrosion, in particular stress corrosion cracking of metals and alloys. Existing methodologies for testing the potential to corrosion cracking are divided into three groups, depending on the way the stress state is created:

- methodologies, where constant displacement of the specimen is created;
- methodologies, where constant load on the specimen is applied;
- methodologies, where constant strain rate is applied.

Tests are usually carried out using specimens of the metal formed as test specimens of specified configuration and dimensions. When selecting the test specimen, the main considerations should be aimed at ensuring the convenience of the experiments and the accuracy and reproducibility of the results. From this point of view, the use of a U-shaped test specimen is the most appropriate. Such a test specimen provides the convenience of creating a controlled stress state - static and/or cyclic- and for the experiments presented below, the chosen approach was loading by pinching the arms - the point of maximum tensile stress is then on the outside of the specimen.

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The load is created by pure bending. The area of the highest stress is focused at the top of the specimen, which can be immersed in the aggressive medium during the experiments.

In this case, a U-shaped specimen with a circular cross-section with a diameter of d = 7.3 mm, a 11.5 mm radius of roundness at the tip and an arm of 38.5 mm was chosen (Fig.1) [3, 4]. This choice was made based on the capabilities of the available equipment (LRu-1 type strength testing apparatus).

The aim of the present task is to investigate the resistance to stress corrosion cracking under static loading of cast steels, in particular 3X14L, BDS 3692-78 in different structural states, using the methodology and equipment for laboratory stress corrosion resistance testing already developed by the author.

EXPERIMENTAL

To develop the required stress in the test specimens when testing their stress corrosion resistance, the relationship between the deformation and the stress inducing it must be known. This relationship must be determined experimentally.

In the experiments, the test specimens are loaded to the pre-selected stress value by achieving the required displacement. The stresses at which the tests are carried out must, as a rule, be within the limit of proportionality (elastic region). However, the laboratory methods for stress corrosion resistance tests usually resort to stresses equal to or slightly higher than the yield point. Testing at such stress values not only allows corrosion potential to be manifested more rapidly, but also allows better reproducibility of results than at lower stresses.

The aggressive environment and the temperature conditions for the test are determined on a case-by-case basis, mainly depending on the type of metal (alloy), but also taking into account the specific task - service conditions of workpieces and alloy products or of experimental interest.

Generally, testing can be carried out in two ways:

- determination of the time to failure of the specimens under the specified conditions - stress value, aggressive medium and temperature regime, i.e. determination of the basic characteristic of stress corrosion resistance;

Fig. 1. Test specimen.

- investigation of the kinetics of crack initiation and growth - for this purpose, a series of specimens preloaded at the specified stress, are placed in the aggressive medium and their load at failure is determined successively at certain time intervals; the kinetics of crack initiation and growth can be judged by the variation of the load at failure, i.e. the incubation period can be determined - no change in the load at failure will be observed; as the crack appears and during its growth, the load-bearing cross-section of the specimen decreases and hence the effort required for its failure will also decrease [3 - 5]. This methodology was chosen for the experiments performed.

Method of work

As mentioned, this methodology provides for the use of a U-shaped test specimen with relatively small dimensions. The most suitable method for obtaining castings of the dimensions and configuration characteristic of the selected test specimen is fusion casting. In order to obtain a casting of the specified dimensions and configuration, several preparatory steps must be carried out to obtain the test specimen.

Design and manufacture of the mould

For the implementation of the method, it is necessary to construct and manufacture the corresponding tooling- the mould for the wax patterns of the castings and for the casting system (Figs. 2, 3).

The preparation of the master pattern and the

Fig. 2. Mould.

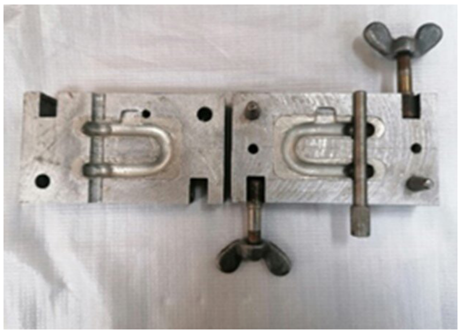

Fig. 3. Open mould.

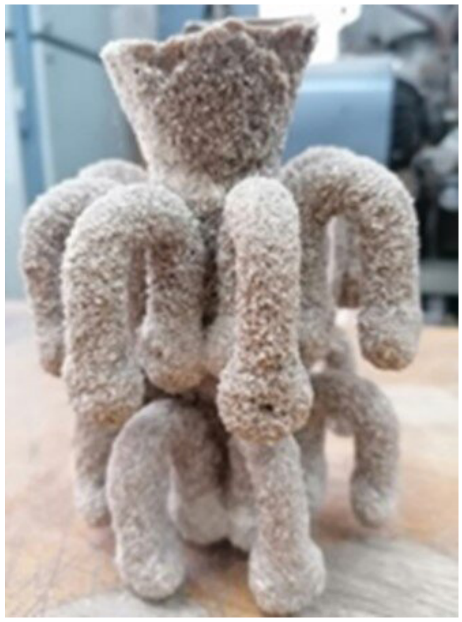

Fig. 4. Casting mould.

final shaping of its workspace by casting with K-154 composition was carried out in the metal casting laboratory of the University of Chemical Technology and Metallurgy.

Fabrication of the casting mould and casting system. In this case, the most suitable type of casting system is the classical one for the method - a centrally located cylindrical collector riser. The specific dimensions of the casting system, or the mould board, are tailored to the characteristics of the melting unit to be used (laboratory induction furnace) and the way the mould is poured (directly from the furnace) - diameter 25 mm and height of the active part 120 mm; the capacity of this casting system is 12 castings. The casting system pattern is made of aluminium alloy. The required wax layer on its surface is applied by repeated dipping in molten pattern composition [6].

The casting mould is made using a moulding compound (Fig. 4). The mould is constructed from five process layers, using silica sand fraction 010 to fix the first layer and 040 for the remaining four layers.

The moulds were fired at the UCTM in a laboratory chamber furnace at 800^{o}C in a support backfill of silica sand.

Manufacturing test specimens

The moulds for the casting of the test specimens were manufactured at the plant of Buser-96 OOD, applying the aforesaid methodology - casting on meltable patterns, which require the production of wax patterns (Fig. 5).

When making the mould board, the casting patterns are mounted on the pattern casting system by brazing.

Removal of the patterns from the finished mould was done by melting in a water bath.

Blending and melting the alloy, pouring the mould. The experiments were designed to use corrosion-resistant, chromium steel grade 3X14L according to BDS 3692-78. The choice of this steel is based on the following considerations:

- it is one of the most common grades of steel from which castings are made for various workpieces, mainly

Fig. 5. Wax patterns.

by the molten pattern method;

- there are no systematic literature data on its stress corrosion resistance.
- Of the corrosion-resistant steels with 12 - 14 % Cr, it occupies an intermediate position in terms of carbon content, making it the most typical representative of this group of steels.

As blending materials, 3X14L steel gates (sprues), low-carbon ferrochrome for composition adjustment and for annealing - FeSi75 and aluminium were used.

Melting was carried out in a crucible high frequency induction laboratory furnace with a crucible capacity of 3 kg. The casting temperature was 1570^{o}C, and was controlled with a Pt-Rh 30/6 thermocouple and RT 384 programmable logic controller. Pouring was done directly from the furnace.

Displacement/stress relation

The relation between absolute deformation of the test specimens and the stress inducing it was determined experimentally using a mechanical testing apparatus type LRu-1. Suitable end-pieces have been designed and fabricated to clamp the test specimen to the loading unit of the apparatus. The absolute and residual strain of the specimen were read using an indicating micrometer with an accuracy of 0.01 mm. The results of this determination are available in previous work by the author [7 - 9].

Fig. 6. Loaded test specimens.

Stress selection

To perform the control test, as recommended, a stress exceeding the yield point was used, with the specific condition being that the residual strain should be around 5 % - i.e. some plastic deformation is realized in the specimens. Using the results of the study of the $\sigma = \sigma(\varepsilon)$ relationship, it was determined that the set condition is satisfied by a stress of 530 MPa (54 kgf mm^{-2}) occurring at an absolute specimen strain of 1 mm, where the residual strain is within 0.05 mm [3]. This stress was created in the specimens during the tests [9].

Selection of aggressive medium

Due to the lack of systematic data for 12 - 14 % chromium, corrosion-resistant steels and in particular for 3X14L, the choice of aggressive medium was made based on literature data according to which corrosion resistant steel 1X18H9L under a load of about 50 kg mm^{-2} in boiling 45 % $MgCl_2$ solution (115 - 125^{o}C) fails in about 8 hours [3, 8], for the present control study the same conditions were adopted [9].

After the sample specimens (castings) were made according to the presented methodology, a series of sample specimens were subjected to heat treatment. The first series was quenched at 1000°C with air cooling, the second series was quenched and tempered at 300°C with air cooling, and the third series was quenched and tempered at 750°C with air cooling [10].

Test specimens were loaded to the specified stress value immediately prior to testing. The specimens were loaded using a screw joint until the specified strain rate (1 mm) was reached, after which the specimens were immersed in a 45 % $MgCl_2$ solution previously prepared and heated to boiling (115 - 125^{o}C) (Fig. 6).

Table 1. Breaking stress of the specimens after submersion in the aggressive solution, MPa.

Time, h	Heat treatment mode		
	Quenched 1000°C	Quenched and tempered at 300°C	Quenched and tempered at 750°C
0	1341.5	1457.5	1510.2
24	786.7	1592.6	1407.5
48	600	1514.8	1512.2
72	180	1410.7	1523.2
96		1491.2	1490.6
120		1491.2	1584.1
144		1431.9	1414.6

RESULTS AND DISCUSSION

The failure stress of the sample specimens of each group was determined at intervals of 24 hours. The results of the test are shown in Table 1 and graphically in Figs. 7 - 9.

For all three series of test specimens, a clear trend of decreasing failure stress with increasing time, spent in the aggressive solution was observed. The decrease is most intense in the case of the quenched test specimens,

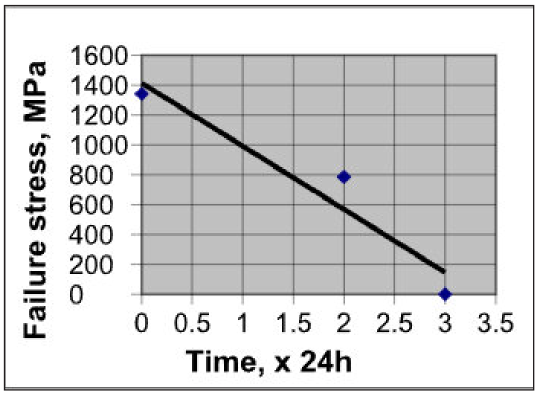

Fig. 7. Dependence of failure stress on time of treatment in the aggressive solution - quenched test specimens.

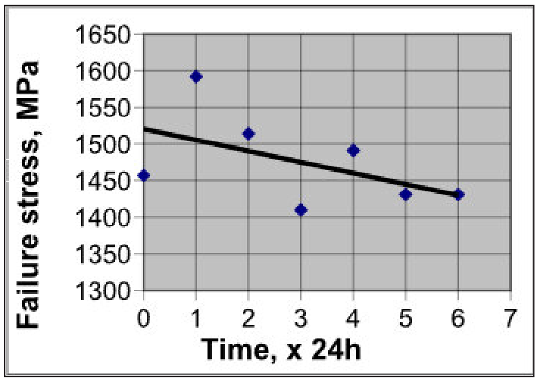

Fig. 8. Dependence of failure stress on time of treatment in the aggressive solution quenched and tempered at 300°C.

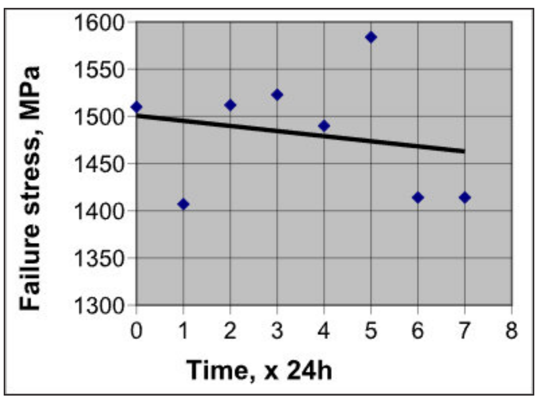

Fig. 9. Dependence of failure stress on time of treatment in the aggressive solution - quenched and tempered at 750°C.

which could be explained by the fact that in this condition the structure is characterized by large internal stresses. The same logic is followed by the change of the failure stress in the specimens tempered at 750°C, where the change was the weakest. The comparative change of the failure stress of the three series of test specimens is shown in Fig. 10.

CONCLUSIONS

The conclusions that can be drawn from the methodology thus established and from the study of the corrosion cracking of cast, high alloy chromium steel under different heat treatment modes are:

- A methodology has been developed for testing the stress corrosion performance of cast steels. For this purpose:
  - a test specimen of the required configuration and dimensions was selected;
  - the necessary equipment for casting test specimens by the molten pattern method was designed and fabricated;
  - the necessary accessories for the LRu-1 mechanical testing apparatus were designed and manufactured- end-pieces for clasping the test specimen, a strain gauge and a stress increase system.
- The methodology can be used to determine the stress corrosion resistance of other alloys, subject to the capability to make castings out of them by the classical version of precision casting.
- A control study was carried out, applying this methodology, which included:
  - making wax patterns and casting moulds for test specimens;
  - casting of test specimens from 3X14L steel;
- A comparative study of the stress corrosion resistance of 3X14 steel castings in three structural states - quenched, quenched and tempered at 300°C, and quenched and tempered at 750°C, under the following conditions: stress 500 MPa and aggressive medium 45 % $MgCl_2$ solution at temperature 115-125°C.
- It was established that the most intensive failure was observed in the quenched specimens, and the most resistant steel was that, subjected to heat treatment consisting of quenching and tempering at 750°C.

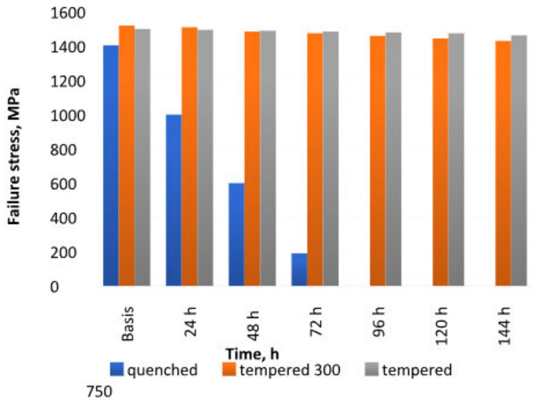

Fig. 10. Comparative diagram for the change in failure stress of the three series of test specimens.

To summarize - the corrosion cracking resistance of high alloy chromium steels can be modified with proper casting cleaning selections and selection of appropriate thermal treatment processes.

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