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LOW FREQUENCY INDUCTION HEAT TREATMENT INFLUENCE ON THE STRUCTURE AND MECHANICAL PROPERTIES OF C TYPE SUCKER RODS (35MN16)

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Lucrarea îşi propune să arate influenţa aplicării unui tratament termic de încălzire prin inducţie utilizând curenţi de frecvenţă joasă în scopul îmbunătăţirii comportării la oboseală a prăjinilor de pompare tip C (material 35Mn16). Încălzirea pentru tratamentul termic de normalizare s-a efectuat la o temperatură de încălzire de 910 – 940^{0}C, cu o viteză de încălzire de 20 ^{0}C/s. Rezultatele obţinute au evidenţiat creşterea tuturor caracteristicilor mecanice: limita de curgere, rezistenta la rupere, rezistenta la oboseală a epruvetelor încălzite prin inducţie utilizând curenţi de joasă frecvenţă, precum şi uniformizarea structurii şi finisarea granulaţiei. Simularea comportării la oboseală a acestor prăjini de pompare s-a realizat cu programul SolidWorks, utilizarea corectă a programului de analiză cu elemente finite determinând alegerea unei soluţii optime cu costuri minime.

This work attempts to demonstrate the influence of low frequency induction heat treatment in improving type C sucker rods' (35Mn16) behaviour to fatigue. Heating for annealing was achieved at a heating temperature of 910 – 940 ^{0}C, at a heating rate of 20^{0}C/s. The results emphasized the increase of all mechanical characteristics: yield strength, ultimate strength, fatigue strength of the heat treated samples as well as structure uniformizing and grain refinement. Simulation these sucker rods' behaviour to fatigue was achieved by using SolidWorks. The correct use of the analysis with finite elements allows the choice of an optimum solution at minimum costs.

Keywords: Sucker rods, annealing, heating by induction, low frequency currents, fatigue, computer aided design

1. Introduction

Among all the elements of the pumping system, the sucker rods have the greatest influence on the operating and the performances of the oil extrusion systems. Their mechanical characteristics limit the loads that can be transmitted,

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and the rods' ability to send inputs determines the good operation of the pump. The pumping systems which use sucker rods now operate in aggressive environments while producing the oil. The combined effects of a corrosive environment and significant mechanical loads contribute to the frequent appearance of the sucker rod failures during the exploitation [1].

The evolution of the sucker rod exploitation technologies as well as the evolution of the sucker rod production technologies led to the diversification of the types of rods and their constructive and technological variants.

The phenomenon of fatigue failure of the materials which appears during cyclical solicitations is extremely complex. A series of factors such as the shape of the component, its size, the type of solicitation, the state of the surface, the temperature of the environment influence its strength to the cyclical solicitation and the life span of the components. A thorough knowledge and study of these factors allows for a more precise evaluation of the admissible stress. Several technological procedures such as hardening, heat treatment using HFC, different combined thermo-chemical treatments, contribute to the improvement of the fatigue characteristics. In the same way, they influence both the constructive measures and the exploitation conditions.

As a conclusion, to prevent the appearance of unwanted events which can have serious consequences on the human safety as well as on the safety of the environment, it is necessary to know, as much as possible, the behaviour of the material during the exploitation.

By studying the behaviour under fatigue conditions of the conventionally annealed type C sucker rods [2] it was observed that the results are constant along the rods. Great differences which appear at the heat treated rods, between the ends and the centre, can be explained considering a variable heating temperature along the rod. Starting from this observation we achieved the heating in view of induction currents by means of rods annealing.

The aim of the present work is to determine the influence of applying a new heat treatment based on low frequency currents on the fatigue behaviour of sucker rods.

2. Materials and Methods

During the experiments we used the 35Mn16 steel, having the following chemical composition (determined through spectroscopy): 0.395%C; 0.278%Si; 0.85%Mn; 0.0078%P; 0.012%S; 0.89%Cr; 0.044%Ni; 0.199%Mo; 0.026%Al; 0.06%Cu; 0.0057%Co; 0.0021%Ti; 0.0032%Nb; 0.069%V; 0.012%W; 0.0097%Pb; 0.0002%B; 0.0066%Sb; 0.006%Sn; 0.0036%Zn; 0.0075%As; 0.0015%Bi; 0.007%Ta; 0.0018%Ca; 0.002%Ce; 0.0015%Zr; 0.0005%La; 0.025%Se; 0.012%N; Fe balance.

Heating through induction was achieved at a higher speed than heating in the oven. Since the increasing heating speed results in a shifting towards higher temperatures of pearlite transformation, the heating temperature must be established in terms of the type of steel and the heating speed. As the penetration depth of heat is inverse proportional to the frequency [3], to achieve heating at high depths we can use low frequency generators 50÷2500Hz, because at higher frequencies the Kelvin effect of the current prevents us from obtaining a corresponding penetration. The diameter of the inductor is chosen in terms of the diameter of the upset end of the sucker rod and it is recommended that the optimum space between the inductor and the part be 1.5÷2.5 mm to optimise the specific consumption of energy.

For the experimental test we used an industrial frequency generator of 50Hz endowed with a two coil inductor to compensate the inductive reactance and to improve the power factor. Annealing through inductive heating was achieved at a heating temperature of 910-940˚C, with heating rate of 20˚C/s. Tests for mechanical characteristics and fatigue behaviour of the experimental sucker rods were made on an INSTRON 8801 device and the Locati method was used to determine the fatigue strength . Structural investigations of the sucker rods were performed on a Reichert optical microscope. Fatigue behaviour modelling was made by using the finite element. One of the most difficult tasks on structures designing is the one of making prediction concerning their durability, when the variability of the charge follows an irregular spectrum [6]. The 3D modelling and the finite element analysis of the sucker rods were performed using SolidWorks 2009. For the simulation of the real loading cycle of the sucker rod we considered the maximum force $F_{max} = 122000N$ and the minimum force $F_{min} = 72000N$ as oscillating tensile load. The static calculus was achieved by applying F_{max} under the shape of a load distributed on the surface of the free end of the rod. The boundary conditions and the charge are presented in Figure 1.

The model was meshed with tetrahedral elements having 4 nodes. A number of 46162 elements and 30406 nodes were necessary to achieve meshing. We have to mention that refining meshing above the chosen level does not lead to significant -improvement of the result, as is depicted in figure 2.

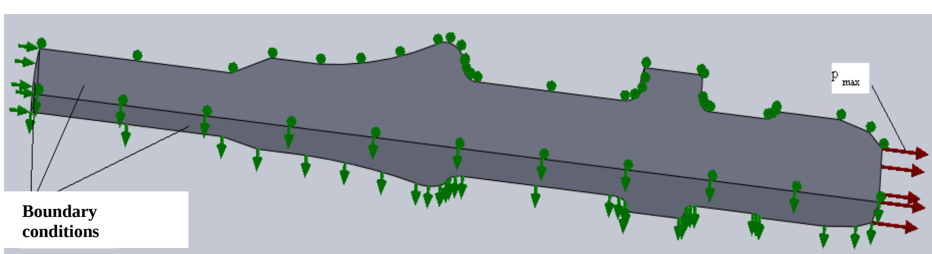


Fig. 1. Boundary conditions and load

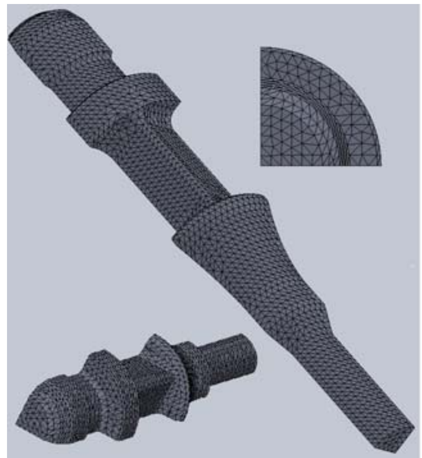


Fig. 2. Meshing the model

3. Experimental results and Discussion

From the type C sucker rods, obtained through heating treatment using low frequency currents, samples for tensile test, notch toughness and fatigue have been executed. The measured characteristics are presented in table 1 and figs 3, 4.

Table **1**

Mechanical properties of the experimental materials

Heating	Yield Strength $R_{p0,2}$ MPa	Fracture strength R_m MPa	Elongation at fracture A_5 %	Toughness, KCU J/cm^2	Necking, Z %	Fatigue strength σ_{-1} MPa
Conventional annealing	469	696	19.7	67	51.8	412
Inductive annealing with low frequency currents	619	780	21.8	99	55	486

From the metallographic analysis conducted on the Reichert metallographic microscope it is observed that the structure of the steel samples - consists in ferrite and pearlite with Widmanstätten aspects in the case of untreated steels. By applying annealing with conventional volume heating homogenizing of the structure and the diminution of the Widmanstätten aspects are generated. By applying annealing with heating through low frequency currents induction the levelling of the structure, the grain refinement and the complete elimination of the Widmanstätten aspects are generated.

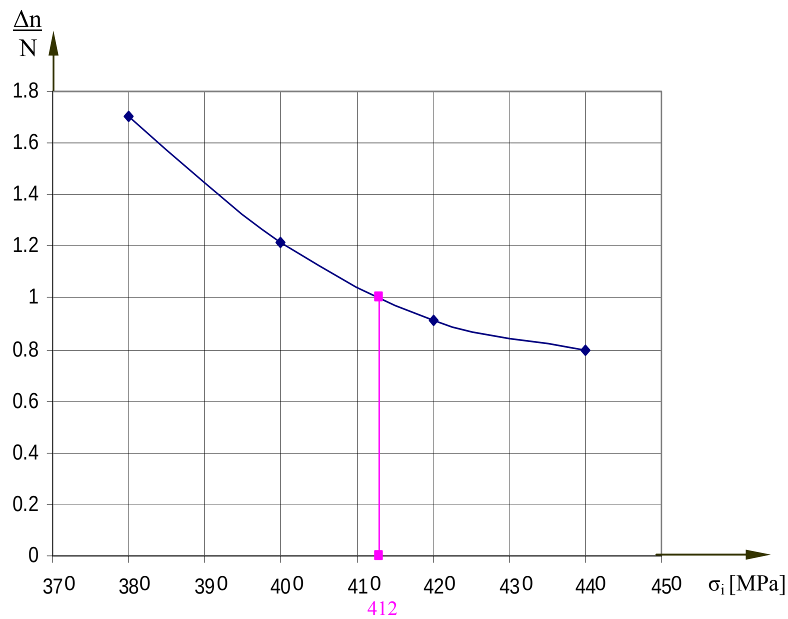


Fig.3. Fatigue limit for conventionally heated sample ø 19, made of 35Mn16. Axial stress fatigue $\sigma_D = 412$ MPa

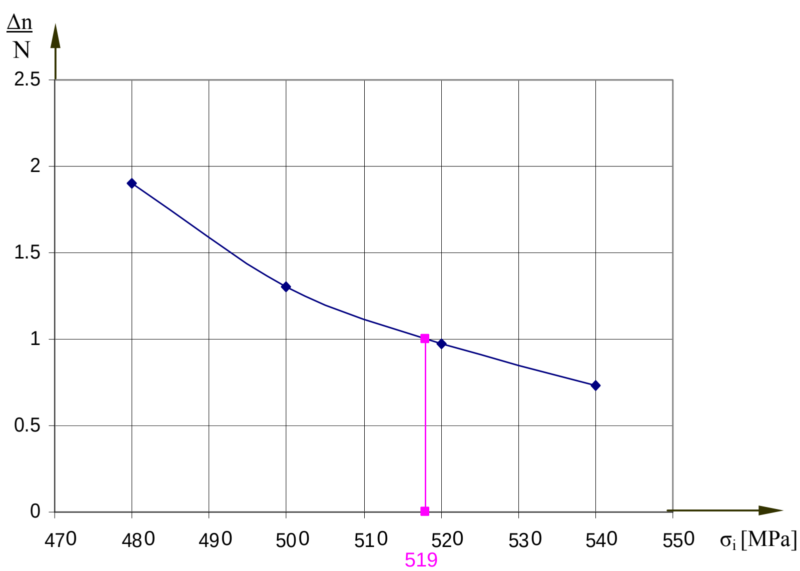


Fig.4. Fatigue limit for sample heated through low frequency induction ø 19, made of 35Mn16. Axial stress fatigue $\sigma_D = 519$ MPa

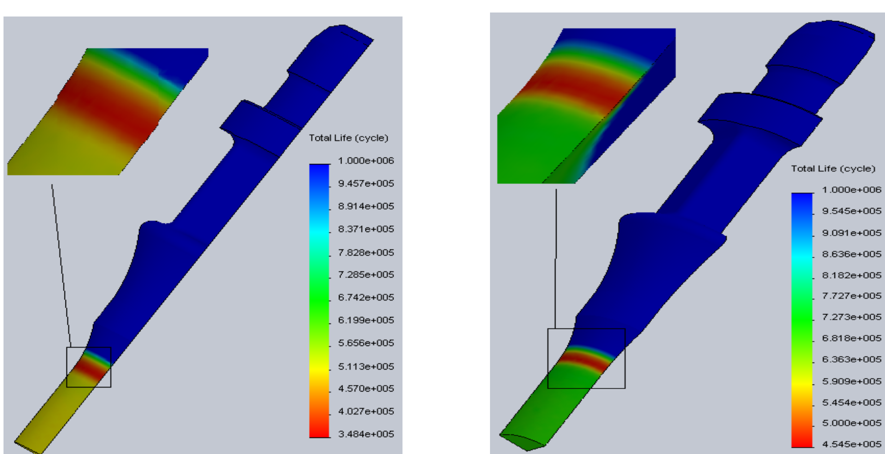
By analyzing these data it is observed that annealing with heating by inducing low frequency currents for the type C sucker rods conducts to much better characteristics than the ones imposed by the standard [5].

a) b) c)

Fig.5 - Micro structural aspect of the sample Φ 19mm taken from the body of the rod, tested under axial fatigue, made of 35 Mn16 steel: a) untreated, b) conventionally heated, c) heated by low frequency current induction (nital etching 2%, x100)

4. Failure behaviour modelling of C type sucker rod

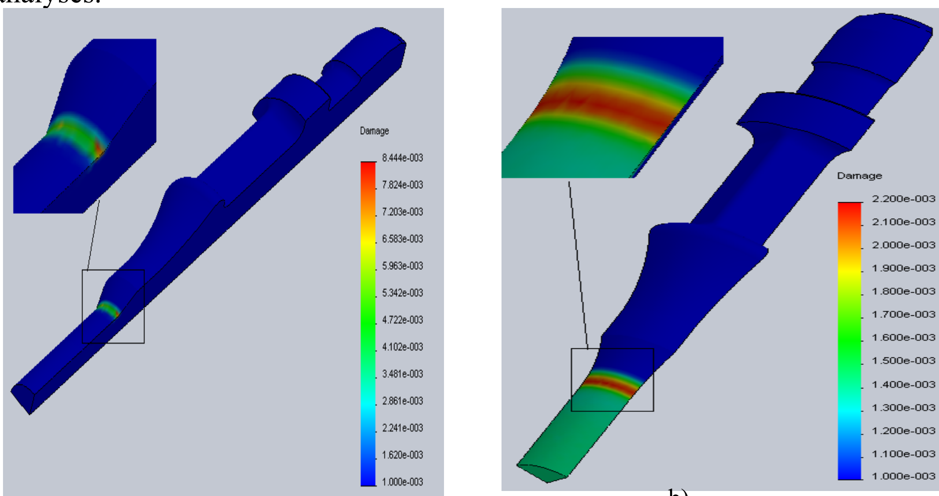
In the case of resistance structures with complex geometries, where the presence of the stress raisers is inevitable, the experimental evaluation methods of their durability are either impossible to apply or very expensive. The development of the computer technology, and in parallel, of the calculation techniques allowed deeper and deeper involvement of the computer aided design methods while evaluating the integrity of such structures. The method of the finite elements analysis proved to be a real success to determine the strain concentration quotients, without needing further mechanical tests of the real structure to establish them. This advantage is currently used in the fatigue calculus in the field of the mean and high durability, knowing that in general fatigue fracture is produced in the areas where there are stress raisers. In order to emphasize the effect produced on the lifespan of the material 35Mn16 after applying the treatment of heating by inducing low frequency currents, simulations were conducted under the same conditions as for the conventionally heated material.



a) b)

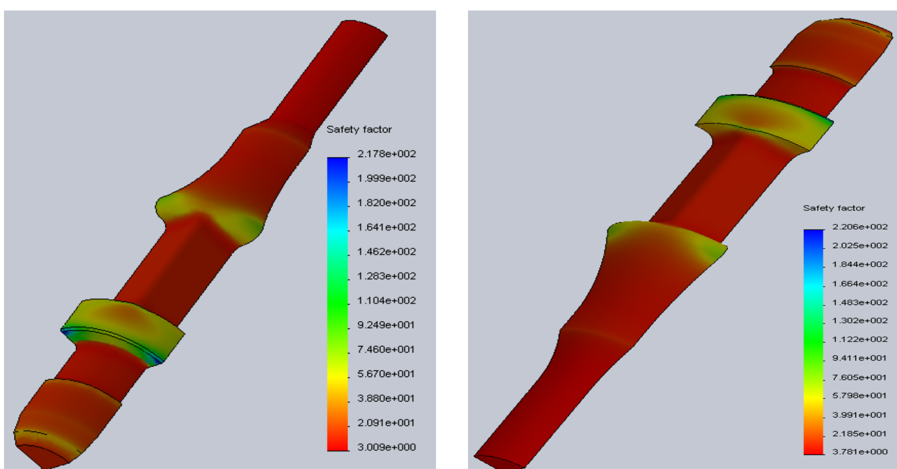
Fig. 6. A lifespan represented for the nodes of the structure in the case of the steel 35Mn16: a) conventionally heated; b) heated by inducing low frequency currents

Figures 6, 7 and 8 present the estimate lifespan, the distribution of the cumulated failures as well as the distribution of the safety quotients specific for these analyses.



a) b)

Fig.7. Distributing failures after 1000 cycles of strain in the case of the steel 35Mn16:
a) conventionally heated; b) heated by inducing low frequency currents



a) b)

Fig.8. Distribution of the safety quotients in the case of the steel 35Mn16:
a) conventionally heated; b) heated by inducing low frequency currents

5. Conclusions

By applying annealing by means of low frequency currents for the type C sucker rods the following advantages are obtained:

- The losses of energy which is necessary for heating the oven elements are eliminated;
- The necessary time to heat the oven is eliminated;
- The losses through convection and radiation are eliminated because heat is locally generated directly in the part;
- Internal strains induced by conventional volume heating are eliminated and at the same time the phenomena of oxidation and decarburization is decreased.

The 3D modelling and finite element analysis of the sucker rod achieved through SolidWorks 2009 has indicated that the fatigue crack is localised at the ends of the central area of the sucker rod where the transition from a diameter to another introduces large strain concentrations.

By applying heat treatment through induction the life span increases significantly – from approximately 3.5×10^5 to 4.5×10^5.

The distribution of failure after one thousand cycles of strain decreases from 8.444×10^{-3} to 2.2×10^{-3}. An increase of the value of the safety quotients also appears in both cases.

The correct use of the finite element analysis software makes it possible for the engineer to adopt an optimum solution with minimum costs.

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