FRACTURE OF STEEL AND CAST IRON AT LOW, ROOM AND HIGH TEMPERATURES

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ABSTRACT

Non-metallic inclusions in steel and graphite ones in cast iron,which are non-coherent with a metallic matrix,are concentrators of stresses and as consequence of this produce a pronounced effect on mechanical and service properties of steel and cast iron.In the sense that properties of these alloys are determined by their resistance to fracture indexes,which enable to evaluate quantitatively the impurity of alloys with inclusions were suggested;the function of the inclusions in processes of initiation and propagation of microcracks at low,room and high temperatures was ascertained as well.

KEYWORDS

Cast steel,cast iron,non-metallic and graphite inclusions, microcracks,fracture,low temperatures,thermal shock resistance,thermochemical erosion.

INTRODUCTION

The effect of non-metallic and graphite inclusions on mechanical properties of steel and cast iron has been studied completely.The shape,the quantity,the size and the nature of inclusions location are the basic characteristics determining the effect of inclusions on the alloys properties.For non-metallic inclusions the composition of which as opposed to graphite vary within wide limits,their physical and mechanical properties are of importance: coefficient of thermal expansion,modulus of elasticity,hardness,strength,etc.

Concentration of thermal stresses around inclusions,their low mechanical properties and non-coherence with a metallic matrix makes the inclusions potential microsources of metal fracture.Initiation of microcracks in non-metallic and graphite inclusions has been studied in many works.Therewith the opinions of different authors as to the function of non-metallic and graphite inclusions in initiation and propagation of microcracks in steel and cast iron are very discrepant. The above outlines currently topical problem of elaboration of the methods, which provide to evaluate quantitatively the role of non-metallic and graphite inclusions in the processes of the fracture of ferrous-carbonic alloys.

EXPERIMENTAL

It is well known that the more is non-metallic inclusions in cast steel and graphite inclusions in cast iron as well as the higher is the parameter of inclusion shape (relation of maximum size to minimum one) the lower the mechanical and the service properties will be. In this connection Uzvak V. and Volchok I. had suggested to determine the inclusion index, which is dimensionless integral index the value of which is related to both quantity and shape of inclusions.

Indexes of inclusions /I_i-for steel, I_g-for cast iron/ were determined by methods of quantitative optical metallography. They were the ratio of the sum of the maximum size of inclusions to the length of the arbitrary secant crossing them.

Methods for quantitative evaluation of the role of non-metallic and graphite inclusions in processes of fracture were elaborated and they are based on the procedure of quantitative metallographic analysis. In quise of destruction characteristics, determined by a calculation method with the use of optical microscopes of ± 10% accuracy have been chosen: the parameter A_c of relationship between the microcracks formed in inclusions and extending through them and the parameter of the contribution of inclusions to destruction /A_i-for steel and A_g-for cast iron/, the parameter equal to the fraction of inclusions which caused the formation of microcracks and hanced their propagation. Tests had been carried out on flat samples by means of static and cyclic loading. Tensile tests were carried out over the temperature range from -120 to 20°C for steel and from 20 to 900°C for cast iron by measuring the applied force and the residual strain samples.

Strength and plasticity indexes of steel and cast iron were determined on cylindrical samples of 10mm diameter, fatigue strength was determined by the circular bend on a basis of 10^7 cycles, low-cyclic fatigue strength was determined on a flat samples by the method of pure bending with a residual strain of 0.45%. The effective surface energy was determined on flat samples 100x100x1.5 mm with the central hole and two fatigue cracks. Cast iron heat resistance (the number of cycles to failure) was determined with the help of high temperature microscope, on samples of 3x3 mm section, subjected to tensile test with 15 MPa constant stress and to thermocycling as per condition 500 700°C. Cast iron resistance to thermochemical erosion was judged by the rate of its oxidation in the air and dissolving in the glass mass heated to 1100°C (immersion of samples into a molten glass was carried out over 2.5 hours on a frequency of $3c^{-1}$) as well as by the changing the surface roughness of the samples.

EXPERIMENTAL RESULTS

Fracture of Steel. The effect of the shape, type and quantity of non-metallic inclusions on the micromechanism of the cast steel fracture was studied. Three fractions of the medium-carbon steel of the same composition after deoxidation with aluminium and yttrium had three types of inclusions according to classification of S.Sims and F.Dahle: globular yttrium oxysulphides of type I, film ferric-manganese sulphides of type II and dense but acute ferric-manganese sulphides and oxysulphides of type III.

While testing the flat samples for tension strong crack formation in steel began at stresses close to yield strength though the first microcracks with a length of some micrometers initiated through the failure of inclusions and their flaking off from the metallic matrix at stresses reaching 0.6-0.8 of the yield strength. Particularly these processes have taken pronounced progression with type II non-metallic inclusions. An average length of microcracks related to type II inclusions was vastly superior to the same index for steel with the type III and in particular type I inclusions (Fig.1). Parameters A_i and A_c for all degrees of deformation had maximum values for a steel with film inclusions and minimum ones for a steel with globular inclusions. From the figure it is seen that the first microcracks in a steel with the type II inclusions (at deformation about 2%) initiated only in non-metallic inclusions /A_c=1.0/ but at deformation about 10% all inclusions contributed to steel fracture /A_i=1.0/. As the area occupied by inclusions was 0.11% of sample area it was possible to state about uneven localization of microcracks or about a particular great role of inclusions in the processes of cast steel fracture.

The influence of temperature on the function of inclusions of three types in processes of fracture of medium carbon cast steel was studied. Fig.2 shows the temperature relationship of the processes of crack propagation at impact bending tests, of total number N microcracks, of the number of cracks N_i related to inclusions, indexes A_c and A_i with a residual strain of 5-8%. From the figure it is seen that there was a definite relationship between the shape (type) of inclusions and the temperature of maximum crack formation: extreme values of the parameters studied corresponded to -30°C for the steel with type II inclusions, to -40°C with type III and -60-70°C with type I inclusions. It should be noted that these temperatures turned to be lower of cold shortness temperature determined on impact samples with fatigue cracks for 20-60°C, it is probably due to more smooth conditions of loading the samples in the first case.

As well it was found that with decreasing in cast Cr-Ni-W steel the sulphur content from 0.041 to 0.009% lowering temperature of maximum crack formation for 20-50°C was observed (Fig.3), then the effect of steel desulphurization was found to be similar to the effect of globularization of non-metallic inclusions.

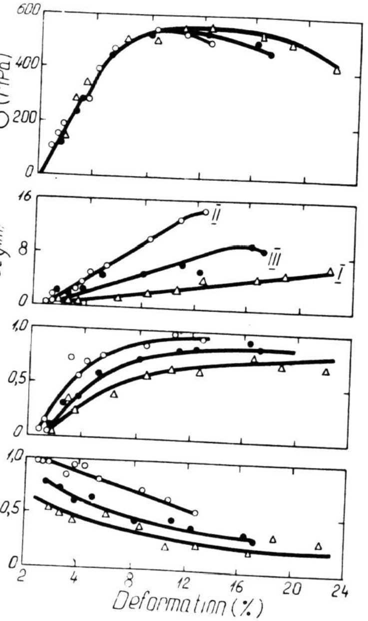

Fig.1.The action of deformation on the value of stresses,average length of micro-cracks in inclusions I_i,parameters A_i and A_c.Figures at curves correspond to the type of inclusions.

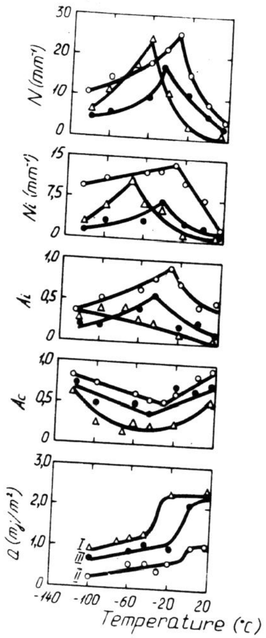

Fig.2.The influence of temperature on indexes N,N_i,A_i,A_c and A, figures at curves correspond to the type of inclusions.

The adoption of the quantitative characteristic of inclusions,index open the way for the deriving the correlation re-

lationships of steel properties to the inclusion index and getting more objective assessment of the inclusion action on the steel quality.So for the medium-carbon steel (0.49% C) the following relationships were obtain: relative elogation δ ,impact strength IS,critical fracture temperature T_c,the effective surface energy γ ,the fatigue limit σ_w and fracture toughness K_{1c} to index of inclusions I_i:

$$\delta = 29-2500\ I_i (\%) \quad (1)$$

$$IS = 0.93-82.5\ I_i\ (Mj/m^2) \quad (2)$$

$$T_c = -85+12500\ I_i\ (^oC) \quad (3)$$

$$\gamma = 0.013-0.61\ I_i (Mj/m^2) \quad (4)$$

$$\sigma_w = 395-21500\ I_i\ (MP_a) \quad (5)$$

$$K_{1c} = 48.9-910\ I_i\ (MP_a\sqrt{M}) \quad (6)$$

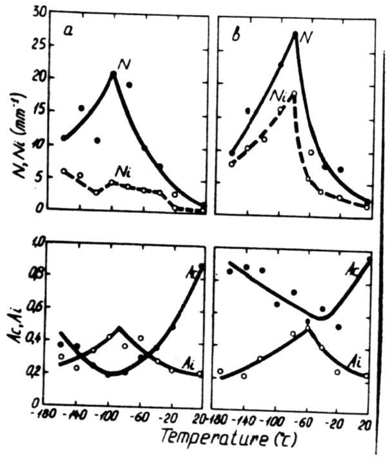

Fig.3.The influence of temperature on indexes N,N_i,A_i and A_c:
a -0.009% S;
b -0.041% S.

From the fracture mechanics it is known that in a rigid body there may be small (microscopic) defects like cracks which do not decrease its brittle strength.In the sense that non-metallic inclusions may be considered as filled voids,an attempt was made to determine the critical size of inclusions which do not cause fracture (cracks) in a metallic matrix.Tests were carried out on the steel with composition:0.20% C,1.64% Mn,0.40% Si,0.27% S,0.16% P,deoxidized with aluminium and titanium;this made possible obtaining the following types of non-metallic inclusions: corrundum,titanium nitrites,sulphides and their complexes as well as those labelled as oxysulphides. Samples were destructed at temperature 20°C by means of tensile tests and flexing (bending deflection 0.45 mm, frequency 1 hertz, number of cycles before destruction 12000-15000). Coefficients of contribution of non-metallic inclusions to fracture were determined on a polished sample surface in the immediate vicinity of the fatal cracks (0.1-0.2 mm).

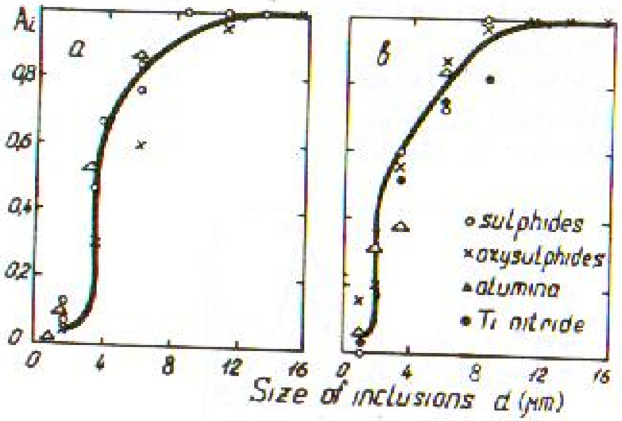

Fig.4. Relation of A_i to sizes of inclusions: a - tension; b - cyclic loading.

From the Fig.4 it is seen that there is a critical size of inclusions which do not cause the formation of cracks in a metallic matrix.

This size is 3.6 m on tension and 2.0 on cyclic loading. From the figure it is seen as well that the critical size is not practically dependent upon the nature of inclusion: with equal sizes of types of inoculatim being studied their contribution to fracture of steel was approximately alike.

Fracture of Cast Iron. An attempt was made to evaluate the effect of the shape of graphite inclusions and the graphite index to resistance of cast iron to fracture under the action of tensile loading at room temperature and under thermocycling loading. The consecutive change of the shape of graphite inclusions from the flake to the nodular one was obtained as a result of inclusions of a melt cast iron with increasing additive of magnesium.

Just as at room so at high temperatures the formation and propagation of microcracks in a grey iron with a flake graphite occured exclusively on graphite inclusions without a perceptible deformation of a metallic matrix (Fig.5a).

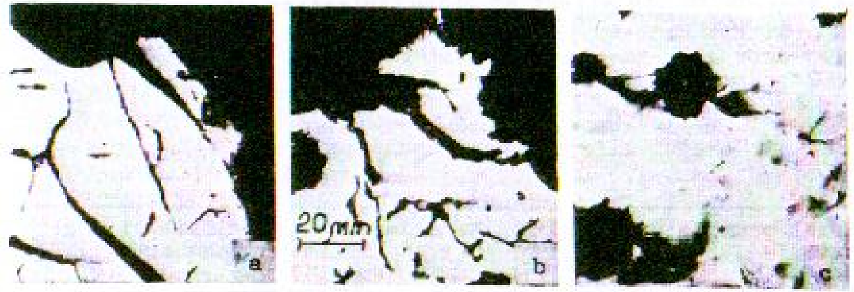

Fig.5. Fracture of cast iron with flake (a), vermicular (b) and nodular (c) graphite.

In a cast iron with vermicular graphite cracks were formed mainly through oblong inclusions normally perpendicular to the action of tensile loading (Fig.5b). With increasing the extent of spheroidizing of graphite inclusions their participation in the formation and propagation of cracks (Fig.5c) was declining as this took place, a nodular graphite played the least role in crack formation and cast iron fracture.

A change of graphite shape from the flake to nodular one resulted in a reduce of the stress intensity factor for inclusions α_σ 3.5 fold, and increase of tensile and crossbreaking strength σ_t and σ_b 5 and 3 fold respectively and relative elongation δ 50 fold. Impact strength K_{1c} therewith increased 7 fold, heat resistance N_t 4 fold (Fig.6). Experimental data shown in fig.5 and 6 point to the availability of successive relationship: shape and quantity of inclusions graphite index fracture mechanics cast iron properties.

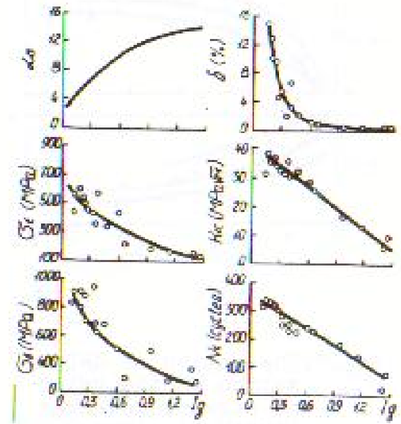

Fig.6. Relation of cast iron properties to graphite index.

The possibility to improve cast iron resistance to fracture at cyclic loading enables to enhance the reliability and useful life of ingot moulds for metal casting, metallic moulds, glass moulding tools and different articles made of cast iron and operating in conditions of thermal shock. Data listed in the table 1 point to the availability of inverse relationship between the graphite index and the service life of ingot mould: with a decrease of the latter i.e.the change-over from grey iron to high-strength cast iron the useful life of ingot moulds increased 2.5-3 fold.

Table 1. The influence of graphite index on the useful life of ingot mould

Metal poured into a mould	Graphite index	Service life of ingot mould (number of filling)
Nickel	1.1 - 1.4	26.0
	0.5 - 0.7	63.4
	0.15 - 0.22	81.5
Copper	1.1 - 1.4	2840
	0.15 - 0.22	7100

At the same time for glass moulding tool,where the roughness of working surface is basic,more complicated relationship between the roughness R_a and the rate of metal dissolving in a melt glass mass was obtained.As it is seen from Fig.7 minimum values of these indexes comply not with a nodular,as it was believed,but with vermicular shape of graphite.

Obtained results may be explained by the following.Thermo-chemical fracture of cast iron under the action of molten glass mass and air occurs primarily in graphite inclusions.Most fine and at the same time rather dense inclusions of vermicular graphite hinder at a maximum erosion processes,and grow of roughness of a working surface of tool.

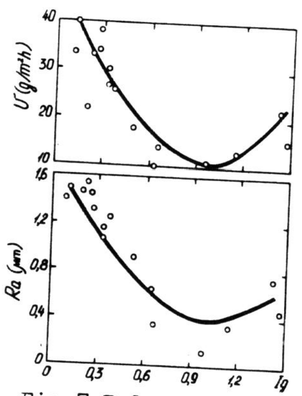

Fig.7.Relation of R_a and V to graphite index.

CONCLUSION

Results of research had proved that in the process of steel and cast iron fracture,regardless of test temperature,70-100% of the first microcracks were initiated on non-metallic and graphite inclusions.Non-metallic and graphite inclusions promote as well the propagation of microcracks in steel and cast iron.