FRACTURE PROFILES OF MODIFIED GRAPHITE CAST IRONS AND SILUMINS

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ABSTRACT

The paper is dealing with an influence of modifiers on the structure and fracture of some cast materials. Graphite cast irons and silumins belong to the most frequent cast alloys. In both cases the casting properties are influenced by brittle phases remarkably. They are formed during the eutectic reaction (graphite in cast irons and silicon in silumins). The melted metal globular shape modification prior to the casting process influences the mechanical properties with regard to the growth of the above-mentioned phases. The graphite shape changes from lamellar graphite through different transient forms (e.g. vermicular graphite) to the globular type. Simultaneously the morphology of eutectic silicon changes from the plate shape to stick form. Changes of micromechanism of fracture from a transcrystalline cleavage to a transcrystalline ductile failure correspond to the changes of the shape of eutectic phases. In this paper the character of fracture surfaces was evaluated by methods of quantitative microfractography. The fracture profiles were determined by means of a vertical roughness R_v coefficient. The vertical roughness coefficient was found to be related to the changes in fracture micromechanism, mechanical properties and morphology of eutectic phases.

KEYWORDS

cast materials, eutectic phase, fracture profile, quantitative microfractography

INTRODUCTION

An important prerequisite for development of a material for given engineering application with optimum mechanical properties is the knowledge of microstructural details. This demands further development of microstructural investigation methods, first of all methods facilitating quantitative estimates. It is necessary to define the exact interrelationship between the microstructure and mechanical properties of materials. That is why the decisive part of the research activity of the Department of Materials Engineering at the University of Žilina is devoted to the problem of quantification of the fracture surface structure with the aim to predict some of material properties [1].

It is well known that the microstructure and properties of cast alloys can be altered by modification. The addition of small amounts of suitable substances into the molten metal prior to the casting process causes changes either in the number of crystallisation nuclei (resulting finally in particle size) or in the growth of crystallisation nuclei (resulting in different shape of excluded phases).

Modification has a major significance first of all in the case of graphite cast irons [2] and cast alloys on the basis Al-Si [3]. Both are at present the mostly used casting groups of materials. In both cases eutectic reaction is taking place during the crystallisation. During this process a fasette-non fasette type of eutectic is formed (in cast irons austenite-graphite, in silumines solid solution α-silicon). This eutectic reaction results further in the development of a brittle phases, namely graphite or silicon. The morphology of brittle phases affects the mechanical properties of alloys significantly [4,5]. A remarkable dependence of mechanical characteristics on the shape of brittle eutectic phases described by a shape factor $M=4\pi A/P^2$ (A-particle area, P-perimeter of particle) has been found [5,6,7].

MICROSTRUCTURE AND PROPERTIES OF EXPERIMENTAL MATERIALS

As experimental materials the following alloys were used:

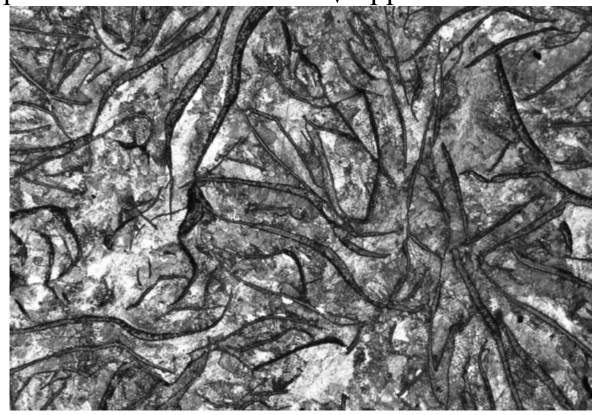
- Grey cast iron of chemical composition 3.6 % C, 2.3 % Si, 0.4 % Mn, 0.02 % S, 0.03 % P modified by various amount (0 – 0.22 %) of concentrated complex alloy of not separated rare earth metals (REM) (min. 97.3 %) with the purpose to achieve the vermicular graphite (VG) morphology [4].
- Nodular cast irons with alternative batch composition with various amount of SiC addition of the following chemical composition 3.6 % C; 2.65 % Si; 0.5 % Mn; 0.002 % S; modified by 2.4 % Litvar 7Ce [8].
- Silumines AlSi10MgMn. Initial melt was not refined and modified, further melts were refined with 1.5 % of salt ALSIL 750 and modified with increasing amount of strontium (0 – 0.05%) in the form of pre-alloy AlSr10 in tablets [5].

Mechanical properties of selected alloys are given in Table 1.

Table 1. Mechanical characteristics of investigated materials

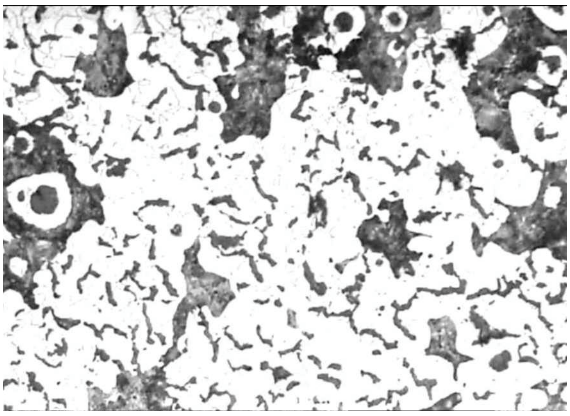
Material	Modification/addition SiC*	R_m, MPa	KC0, Jcm^{-2}
Grey cast iron	-	120	3.6
Grey cast iron	0.12 % REM	124	4.0
Grey cast iron	0.14 % REM	140	10.0
Grey cast iron	0.16 % REM	165	30.8
Cast iron with VG	0.18 % REM	425	35.1
Cast iron with VG	0.20 % REM	460	38.1
Cast iron with VG	0.22 % REM	480	36.9
Nodular cast iron	0.4 % SiC*	545	18
Nodular cast iron	1 % SiC*	539	45
Silumin AlSi10MgMn	-	110	15.0
Silumin AlSi10MgMn	0.01 % Sr	132	18.6
Silumin AlSi10MgMn	0.02 % Sr	130	18.5
Silumin AlSi10MgMn	0.03 % Sr	149	27.4
Silumin AlSi10MgMn	0.04 % Sr	162	43.5
Silumin AlSi10MgMn	0.05 % Sr	161	23.2

Both in graphite cast irons and in cast alloys on the Al-Si base continuous morphological sequences of space shapes were observed. In the case of graphite it is – in general – the morphological sequence from lamellar through vermicular graphite and imperfectly nodular peaks. The coefficient R_v approaches the maximum (Fig.5b). The character and multiplicity

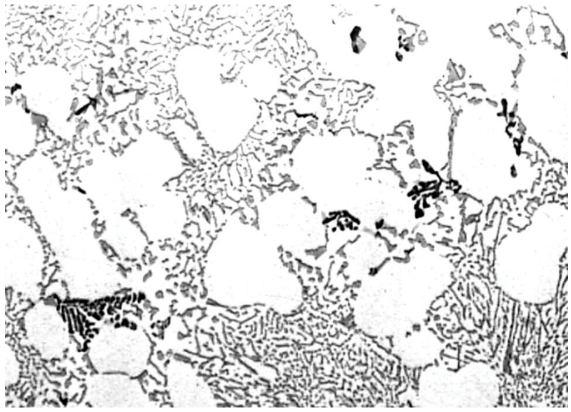


a) pearlitic grey cast iron

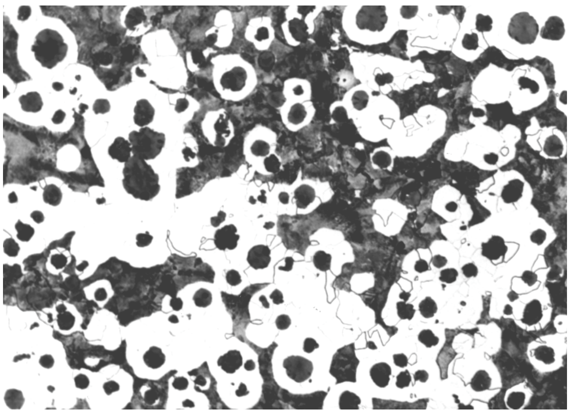
a) not modified



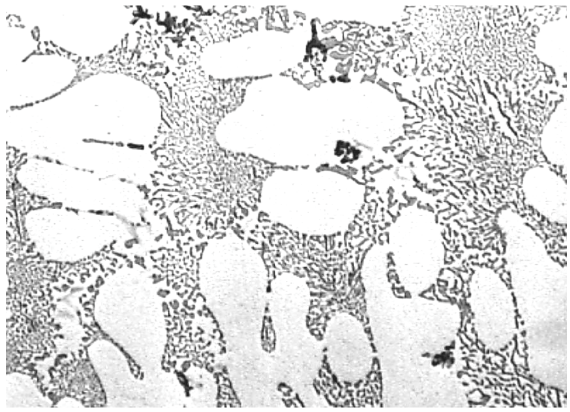
b) ferrite-pearlite cast iron with VG



b) modified with 0.04 % Sr



c) ferrite-pearlite nodular cast iron



c) modified with 0.05 % Sr

Fig.1. Microstructure of graphite cast irons, etched in 1 % Nital, magn. 100 x

Fig.2. Microstructure of silumin AlSi10MgMn, etch. in 0.5 % HF,magn. 400 x

investigated series of alloys, namely basic unmodified melt (corresponding microstructure is shown in Fig.1a) and different batches modified up to 0.16 % grey cast iron (with lamellar graphite). Optimally modified is a batch (0.20 % REM) with vermicular graphite, shown in Fig.1b. Vermicular graphite forms branched space skeletons inside the eutectic cells similarly to the lamellar graphite, but differs by the shape of skeleton branches. For modifiers on the REM base the sudden change of microstructure is the characteristic feature when critical concentration of modifier is reached. The graphite shape changes abruptly into vermicular at the critical amount of modifier, which depends first of all on the chemical composition of liquid metal and chemical composition of the modifier. Changes of impact toughness KC0 (similar tendency was found also for the tensile strength) can be correlated with the changes of graphite shape. For comparison the microstructure is shown in Fig.1c.

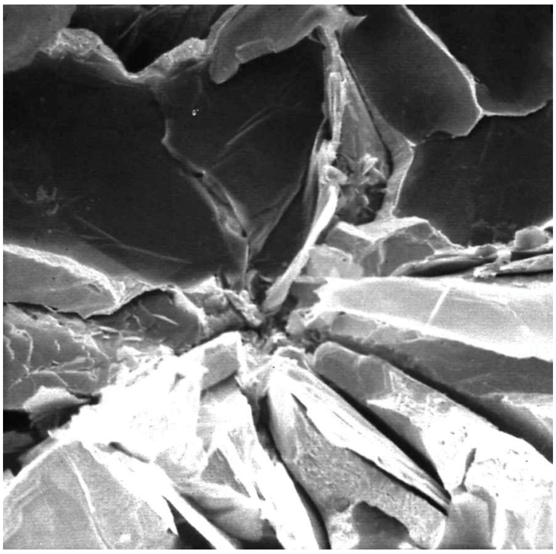
To obtain the optimum shape of eutectic silicon the silumins are modified by Na or Sr in the form of suitable alloys. The initial not-modified microstructure (Fig.2a) is formed by dendritic units of α-phase and needles of eutectic silicon. Modified microstructure is characterised by the presence of rods of eutectic silicon, which are observed on metallographic sections as grains, Fig.2b,c, with the shape dependent on the type of modification. Similarly to the case of cast irons shape-branches units in eutectic silicon can be seen. They are characterised by decreasing branching and increasing globularisation of individual ends of branches for increasing modifier content. The experimentally determined values of toughness can be well correlated with the shape of brittle eutectic phase.

MICROFRACTOGRAPHICAL ANALYSIS

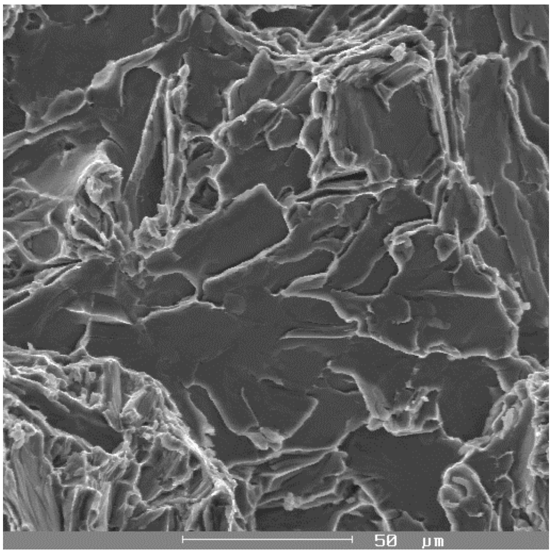
Graphite is acting in the cast irons microstructure as stress riser. The stress concentration effect is dominantly given by the graphite shape. Different shape of graphite influences not only the mechanical properties but also the fracture mechanism. Fig.3a shows the fracture appearance of not modified initial cast iron (pearlitic grey cast iron) for which the graphite cleavage and transcrystalline continuous pearlite matrix cleavage are characteristic. At optimum modifier content on the REM base, the graphite is excluded from the ferrite-pearlite matrix in the vermicular form. On the fracture surface (Fig.3b) significant transcrystaline ductile fracture of ferrite appears. In nodular cast iron produced with the addition of SiC fine globular graphite particles are excluded in the ferrite matrix. With increasing amount of SiC an increasing concentration of ferrite is observed. At higher volume fraction of ferrite in the matrix (Fe80) the transcrystalline ductile fracture of ferrite with dimple morphology (Fig.3c) was observed predominantly.

For quantitative evaluation of fracture profiles cross-sections and sections perpendicular to the fracture surface were prepared. This is documented in Fig.4 for individual materials studied. Fracture profiles of grey cast iron (Fig.4a) confirm the fracture initiation on graphite and cleavage propagation in between the individual graphite particles. The fracture profile of cast iron with vermicular graphite is characteristic by pronounced morphology in the ferritic part of matrix. The profile is formed by dimples (Fig.4b). In the nodular cast iron the fracture profile is characterised by expressed morphology in ferritic part of matrix and it consists of dimples with sharpenings. The fracture path follows the interface boundary ferrite-graphite (Fig.4c).

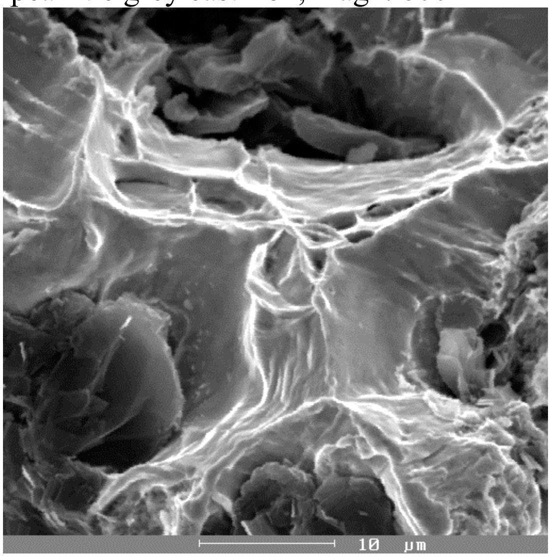
On the fracture surface of not modified silumine AlSi10MgMn facets of transcrystaline cleavage of eutectic silicon are prevailing, Fig.3d, 4d. The breaking of α-phase participates on the fracture surface only insignificantly. Fracture surface of optimally modified silumin (0.04 % Sr) is characterised by marked application of transcrystalline ductile fracture.



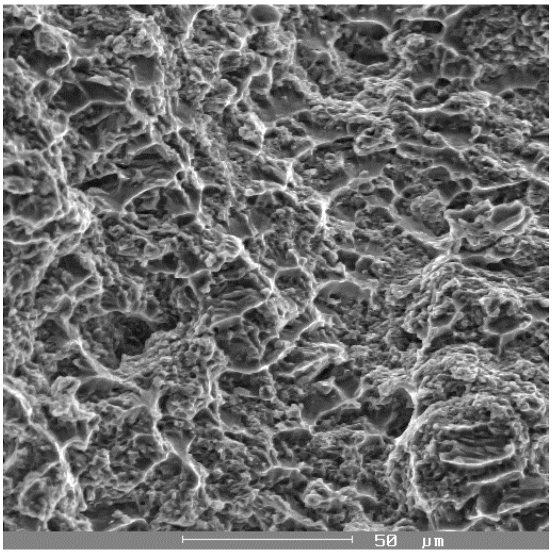
a) pearlitic grey cast iron, magn. 800 x



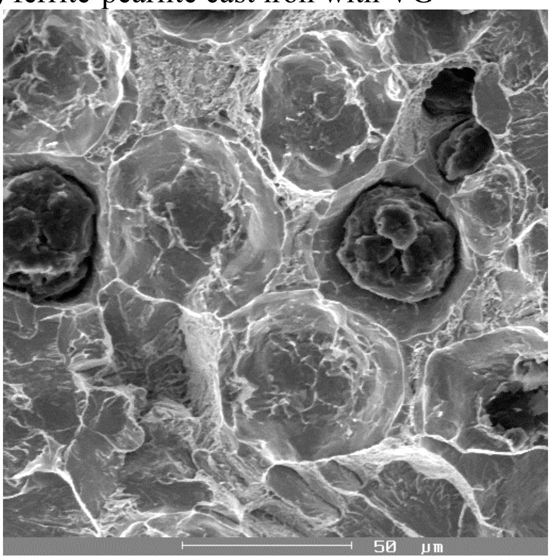
d) not modified



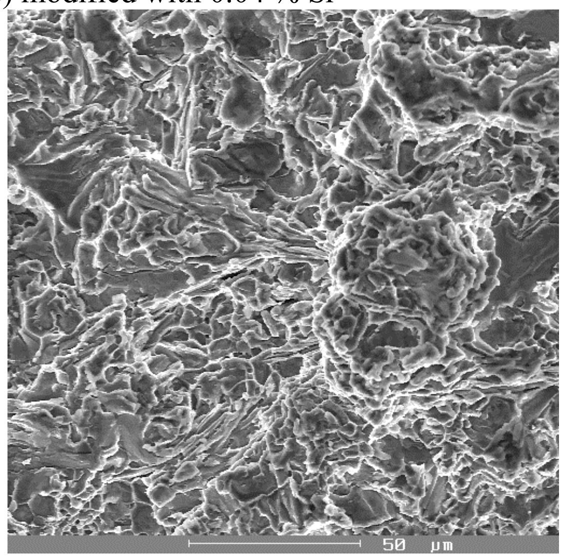
b) ferrite-pearlite cast iron with VG



e) modified with 0.04 % Sr



c) ferrite-pearlite nodular cast iron



f) modified with 0.05 % Sr

Fig.3. Fracture micromechanisms at impact loading, SEM

Dominancy of nucleation phase is caused by microstructural factors, i.e. by the presence of relatively high portion of fine rods or fibres of eutectic silicon (Fig.3e, 4e). They are acting as nucleation centres. From the point of view of fracture trajectory this type of fracture belongs to the ductile one with statistically random trajectory. The nucleation and growth of voids is characteristic for relatively great volume. In upper-modified and over-modified silumin, Fig.3f, 4f the corresponding fractures have a mixed character with various amount of transcrystalline cleavage (of eutectic silicon) and dimples of transcrystalline ductile fracture (of α-phase).

With increasing amount of modificator, which activates more suitable shape of brittle eutectic phase from the point of view of stress riser, in both investigated cases, the transition from transcrystalline cleavage to transcrystalline ductile fracture take palce. The difference is in the formation of ductile compound of eutectic. Ferrite in the cast iron has body centred cubic lattice and in dependence on the stress state the micromechanism of its fracture is changed. On the oter hand in silumin the α-phase has face cubic centred lattice and it is fractured always in ductile manner. That is why the decreasing portion of eutectic silicon cleavage facets causes the transition from cleavage to ductile fracture.

QUANTITATIVE EVALUATION OF FRACTURE PROFILES

The area of fracture surface, S which determines the degree of surface development, belongs to the basic parameters of quantitative microfractography. In general the only exact stereological method of fracture area study is the analysis of fracture profile. Flat sections most often generate the fracture profile. Vertical fracture profile is exactly mathematically treatable representative of fracture area. At fracture profile analyses usually so-called roughness parameters are used. In this contribution vertical roughness parameter, R_v, was used

$$R_V = \Delta y/L' . \ \Sigma P_i \ , \qquad (1)$$

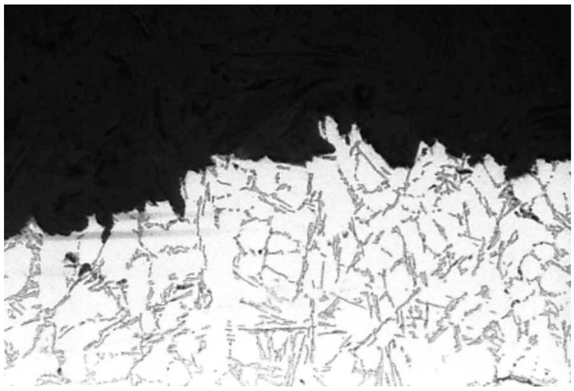
where ΣP_i is the number of fracture profile intersections in the length L' with parallel lines in distance Δy. This dimensionless value, not dependent on the size of hills and valleys in the fracture profile, reflects only the hill/valley proportions. The measured results are given in graphical form in Fig.5 and they are simultaneously confronted with the impact toughness KC0 and the content of modifier.

During the grey cast iron modification with increasing amount of REM a qualitative change of graphite shape (from laminated to vermicular) occurs gradually after reaching the critical modificator concentration. A marked correlation exists (Fig.5a) between the impact thoughness and vertical roughness. For the nodular cast iron in melt with the ferrite fraction 40 % (0.4 % SiC) the coefficient of vertical roughness is $R_v = 0.821$ and in the melt with Fe80 (1 % SiC) is $R_v = 0.992$. Values of R_v increase with increasing portion of ferrite in the matrix, which is in evident correlation with the impact toughness values.

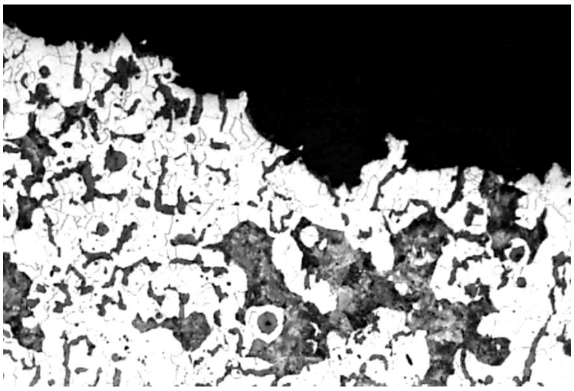
The fracture profile of not modified silumin, formed by profiles of transcrystalline cleavage of silicon can be characterised by the smallest multiplicity (Fig.4d). The coefficient R_v reaches the lowest value (Fig. 5b). From the silumins under investigation contrariwise the biggest

multiplicity has the fracture profile of optimally modified melt (Fig.4e). It is formed by profiles of shallow dimples of ductile fracture and profiles of plastically strained α-base peaks. The coefficient R_v approaches the maximum (Fig.5b). The character and multiplicity

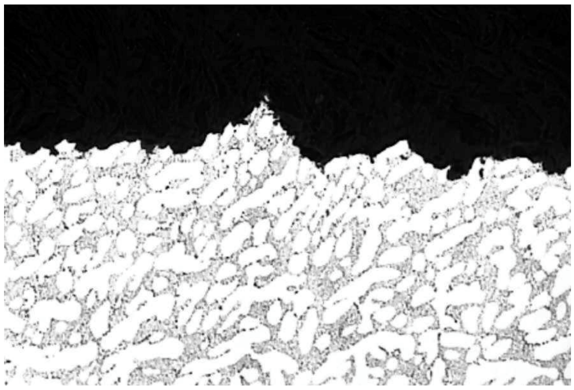
a) pearlitic grey cast iron



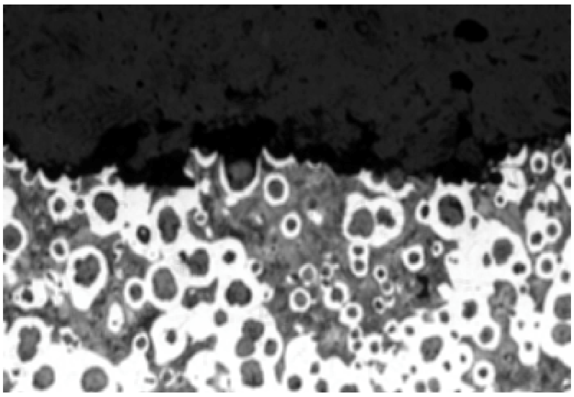
d) not modified



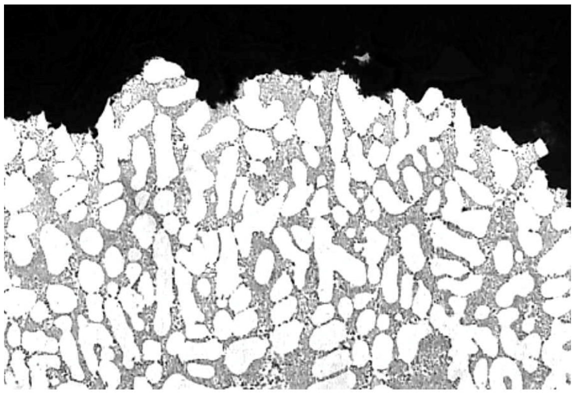
b) ferrite-pearlite cast iron with VG



e) modified with 0.04 % Sr



c) ferrite-pearlite nodular cast iron



f) modified with 0.05 % Sr

Fig.4. The fracture profiles after impact loading, a – non etched, b, c – etched in 1 % Nital, magn. 100 x; d, e, f – etched in 0.5 % HF, magn. 200 x

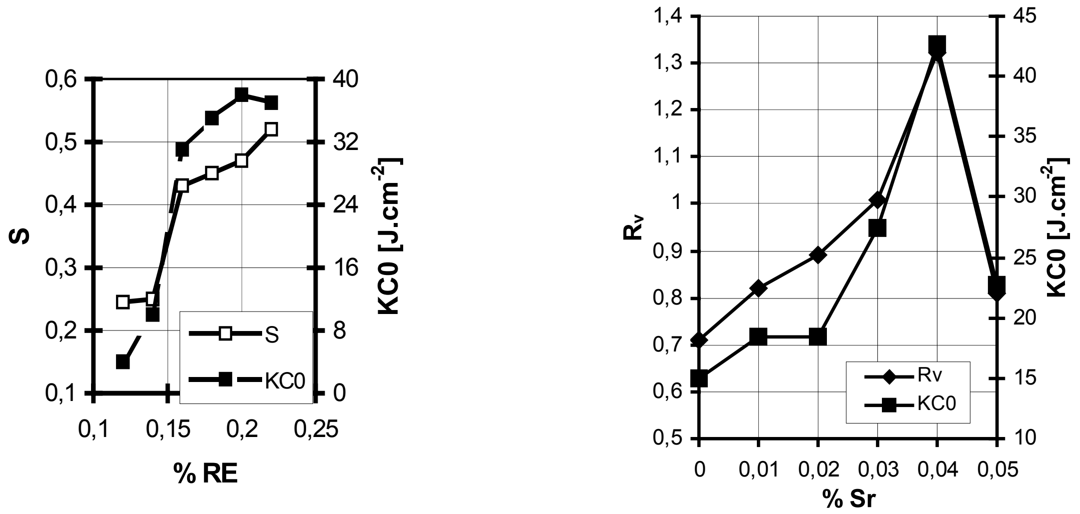


Fig.5. The dependence of vertical roughness coefficient R_v and impact toughness KC0 on the modificator concentration a) cast irons, b) silumins.

of fracture profiles are dependent on the mutual fractions of profiles silicon trans-crystalline cleavage facets and profiles of α-phase ductile fracture dimples.

CONCLUSIONS

Modification (i.e. the addition of components affecting the growth of crystals in molten metal prior casting) significantly affects the morphology of eutectic phases and consequently the mechanical properties of cast materials are changed. On examples of cast iron modified by REM and sub-eutectic silumin modified by strontium it has been shown that the value of fracture profile vertical roughness coefficient R_v sensitively depends on the change of fracture surfaces morphology. Significant correlation with impact toughness of investigated material was found. The R_v value can be thus considered a quantitative microfractographical characteristic suitable for more detailed description of fracture surfaces.

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