

## Numerical Analysis of Stress States with the Spheroidal, Lamellar and Vermicular Type of Graphite

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The paper is concerned with the analysis of tensile stress conditions and microstructure of cast iron with spheroidal, lamellar and vermicular type of graphite. To prepare a geometrical model, quantitative metallography has been used as it enables us to evaluate the structure of the material on the basis of image analysis. The computing structure model has been created in 2-D area by linear triangular elements. On the basis of real structure of the cast iron with spheroidal, lamellar and vermicular type of graphite, a model was created from numerical analysis of tension deformation conditions by finite element method in ADINA software environment. This calculation program helps to solve a very difficult task and has the advantage that the generated model can reflect the actual geometry of the object very well. For the calculation and following statistic evaluation objects, it is necessary to generate a greater number of geometrical models in the future. This theory on modelling of microstructure of materials and following numerical analysis opens new areas and outlooks for usage of computing instruments when analysing the state of the material structure in the area of tension, absorption or frequency qualities of the material. Stress concentration is increased with irregularities of graphite particles shapes.

**Keywords:** numerical analysis, finite element method, spheroidal type of graphite, lamellar type of graphite, vermicular type of graphite

### 1 Introduction

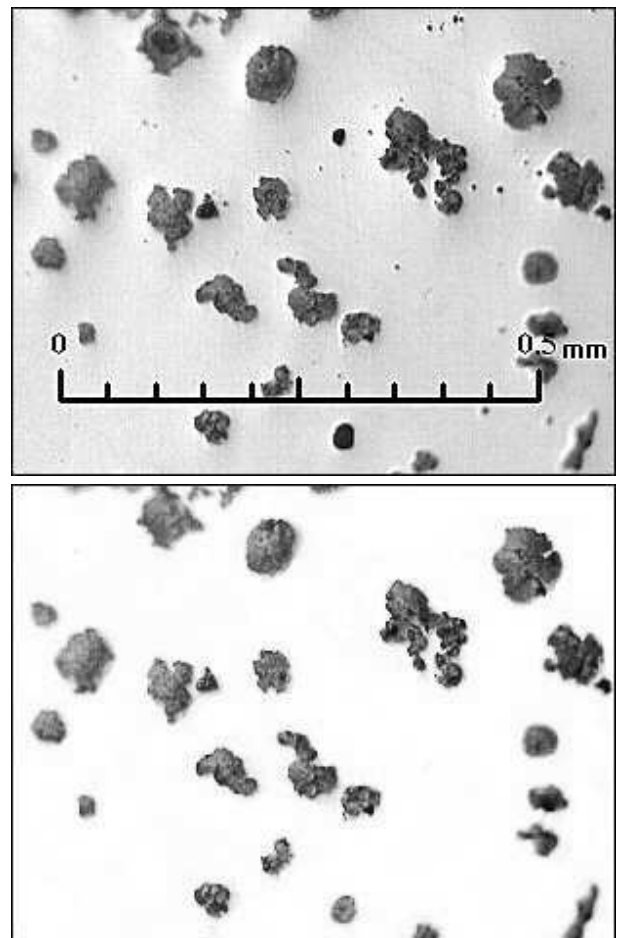
The progress of the numerical processes is closely concerned with the new possibilities and new opportunities of materials engineering including modelling of structures of materials and their simulations for various types of loading. The process of deformation is connected with the foreseeability and understanding of microstructure properties because it is really important for knowledge and specification of defect formations of castings during the process of their production or during the moulding processes [1, 2]. In the recent years, the microstructure modelling and its simulation has played quite important role because of finding out of properties and suitability of usage of the given material before its production.

The finite element method allows us to operate with atypical parameters of microstructure. Nowadays, this method is commonly used in the various scientific fields and spheres. In addition, the most common usage can be found in mechanics, materials engineering, thermodynamics and biomechanics etc. [3, 4].

### 2 Structure of cast iron with the spheroidal shape of graphite (SGCI)

The structure of the basic metallic microstructure of SGCI influences many factors. Two of these many factors are very important because they are connected with the differences of characteristics of austenite transformation which is carried out at unchanged conditions. Influence of chemical composition and influence of cooling speed are the given and important two factors which are mentioned in literature [9]. According to this mentioned fact, there can be the occurrence of ferritic, ferritic-pearlitic or

pearlitic structure for cast irons (see fig. 1, where left part shows the real structure and right part represents the selected model for numerical analysis).

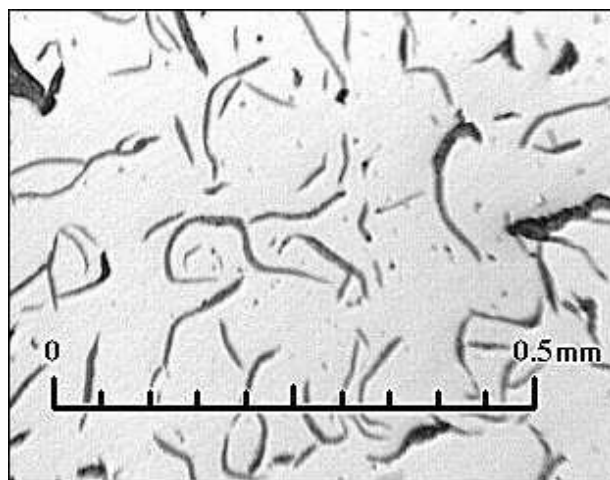


**Fig. 1** Microstructure of SGCI, 100x zoomed

Moreover, structure as well as properties of SGCI can be influenced by alloying process and thermal treatment in some particular limiting cases. SGCI belongs to iron graphite materials and there are also other elements. Its structure consists of basic metallic substance – matrix and the graphite can be found in this matrix. This graphite has a specific shape. It is sort of the regular granular grains. From the aspect of the shapes, this shape of graphite has the least notch or impact effect. Due to this fact, SGCI has very good mechanical properties and therefore SGCI can be included among the most common materials which are suitable for manufacturing of castings [5, 6].

### 3 Structure of cast iron with the lamellar shape of graphite (LGCI)

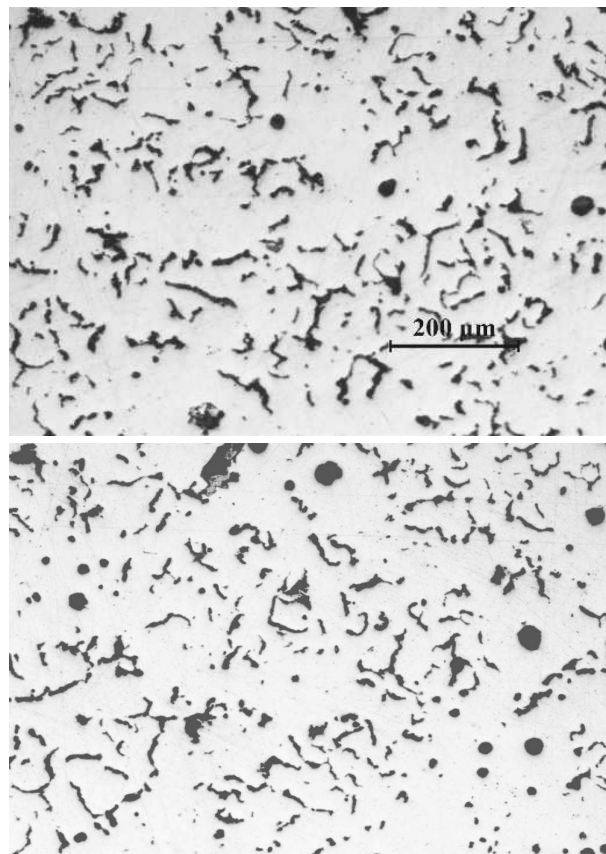
The grey cast iron with lamellar shape of graphite (LGCI) is one of the most used cast irons. When there is the fracture of LGCI, the colour of the area of fracture is grey and therefore, this cast iron is also commonly called the grey cast iron. LGCI contains from 2.5 to 3.5 wt.% of carbon as well as the silicon, the content of which is up to 3 wt.%. This grey cast iron is the cheapest cast metal and because of its properties, it is also one of the most frequently used cast materials. Lamellar graphite is present in its structure while the given structure consists of the pearlitic, pearlitic-ferritic or ferritic metallic matrix together with lamellar graphite (Fig.2), [15], [16].



**Fig. 2** Microstructure of grey cast iron, 100x zoomed

### 4 Structure of cast iron with vermicular type of graphite

In relation to the cast iron with vermicular type of graphite (compacted graphite iron), the particles are elongated and randomly oriented. Moreover, the given particles do not exhibit the sharp edges (the edges are rounded). The two-dimensional image (Fig.3) reveals the part of graphite in the form of spheres as well as individual particles with the vermicular graphite shape. The amount or distribution of the spherical graphite is specified as nodularity [9, 11, 14]. Microstructure of cast iron with vermicular type of graphite is (Fig. 3).

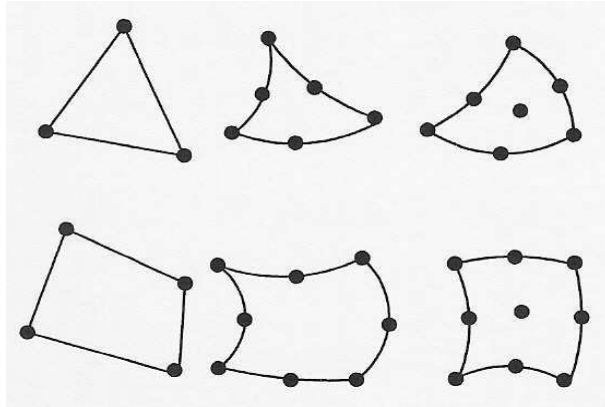


**Fig. 3** Microstructure of cast iron with vermicular type of graphite, 100x zoomed

### 5 Selection of type of finite elements and size of element

The designed model of SGCI material structure was concerned with sensitivity analysis (Tab. 1), relating to change of intensity of stress distribution around the graphitic particles. The graphitic particles are designed as cavities without finite element mesh. On the base of the sensitivity analysis, the determined size of elements was 0.0005 mm. This mentioned size of elements ensures good uniformity and accuracy of resolution and the error of analytical calculation is not higher than 2.5%. Linear triangular elements (Fig. 4) are used for solution. Geometric model was made up for 10% graphitic proportion in structure, the number of particles was 200 ks/mm<sup>2</sup> and size was chosen in the interval from 30 μm to 60 μm and the size of elements is selected to be optimum from the aspect of equations number and it is based on analysis of

sensitivity.



**Fig. 4** The types of elements for 2-D areas

**Tab. 1** Sensitivity analysis toward the size of elements

Size of elements	$\sigma_{yy}$	$\sigma_{zz}$	$\sigma_{yz}$	$\sigma_{HMH}$
0.01	1.215	0.0516	0.012	1.042
0.009	1.209	0.0461	0.0033	1.038
0.008	1.208	0.0464	0.0055	1.036
0.007	1.225	0.0371	0.0185	1.059
0.006	1.489	0.146	0.048	1.211
0.005	1.501	0.16	0.028	1.206
0.004	1.780	0.246	0.0011	1.388
0.003	1.947	0.271	0.0060	1.510
0.002	2.385	0.384	0.013	1.819
0.001	2.800	0.310	0.0069	2.247
0.0009	2.780	0.285	0.164	2.270
0.0008	2.904	0.266	0.048	2.369
0.0007	2.861	0.237	0.0821	2.358
0.0006	2.925	0.215	0.0864	2.436
0.0005	2.931	0.180	0.0089	2.467
0.0004	2.918	0.146	0.013	2.479
0.0003	2.916	0.107	0.007	2.507

Where  $\sigma_{yy}$  – stress in the direction of loading, [MPa];  $\sigma_{zz}$  – stress which is perpendicular to direction of loading, [MPa];  $\sigma_{yz}$  – shear stress, [MPa];  $\sigma_{HMH}$  – equivalent stress with reference to HMH theory, [MPa]

## 6 Numerical model

The shape of the graphitic particle has a significant influence on size of eigenfrequencies as well as there is the influence on state of surrounding stress. If we want to evaluate the quality of graphitic particle, we have to determine some geometric characterizations which describe the mentioned particle. The given determination is also closely connected with the method of measurement of these characterizations [7]. The precise description of boundary relating to graphitic particles can only be obtained during the process of evaluation of results of FEM analysis. This partial restriction is caused by impossibility to obtain any other description of boundary. It can be done only by help of mesh of finite elements.

The first phase of preparation of models is concerned with determination of basic model properties. Matrix

could be considered to be a homogenous structure with the linear dependency based on stress-strain state. Graphitic particle could be the cavity which could be designed in a specific way and it means that the mesh of the finite elements would not be created in the area of this cavity. This type relating to modelling of graphitic particles is possible because of their properties: low tension and frequent decohesion from matrix. Calculation as well as statistic evaluation of results could be done only after generation of large number of geometric models and in this case, the generation should be done for approximately 750 models. During the solving of given task, we decided to create the automatic model generator which operates on the basis of generating of random numbers [8], [10], [12], [13].

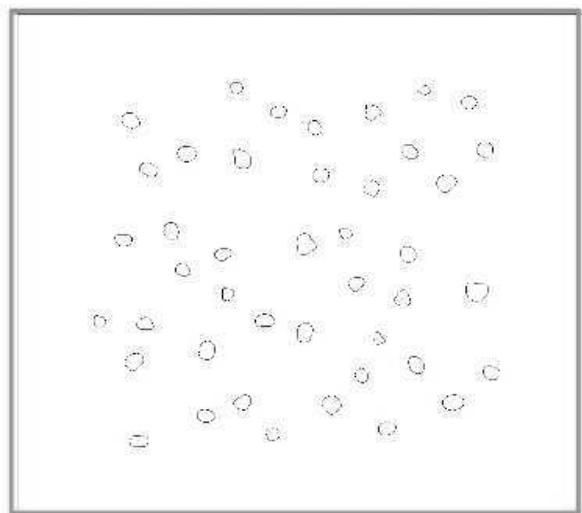
From the point of view of materials engineering, the preparation of geometric model is closely connected with the utilization of characteristic data of SGCI (for purpose of definition of input data). The mentioned characteristic data were obtained on the base of visual image analysis of the experimental material:

- number of graphitic grains for 1 mm<sup>2</sup>: 100 ÷ 300 units,
- average diameter of graphitic grain: 0.01 ÷ 0.08 mm,
- area proportion of graphite in the structure: 4 ÷ 12 %.

The portion of graphitic skeleton depends on crystallization rate (growth is subjected to diffusion of carbon) and amount (proportion and number) of eutectic units especially depends on number of nuclei in molten mass (treating agents). These two mentioned factors have significant influence therefore they are the determinative factors for area proportion of graphite in the structure. On the base of the given mentioned fact hereinbefore, we generated the mesh from points which were connected together and these points can be also understood as representatives of potential centres of graphitic particles. The auxiliary parameter was used for their generation. This auxiliary factor specifies minimal distance between particular graphitic particles. For determination of the given diameter of graphitic particle, we have to generate the auxiliary mesh of points with the sufficient density, for example 100 x 100 points and then we can specify the number of points which belong to individual centres of graphitic particles. The mentioned process is the principle for determination of area proportion for graphite and it is in relation to the individual graphitic particles with the respect to number and size. According to this fact, it is possible to determine the diameter of the individual graphitic particles. This type of change relating to generation of models is connected with the elimination of many problems including size, distribution and number of graphitic particles. On the other side, the diameter of particle can be understood as function of mutual position of graphitic particles and it means that there is not any possibility of occurrence of such particles which would be disproportional from the aspect of “largeness” or size and it also means that there is the elimination of occurrence of too “small” particles of spheroidal graphite. According

to these properties, the algorithm was supplemented by control of scattering, relating to size of graphitic particles. In the case that the given scattering runs over the determined values, the selection relating to centres of graphitic particles is not suitable for any other analysis and therefore these unsuitable particles are not utilized for any other analysis. The algorithm which was made in this way fulfils all qualitative as well as quantitative parameters. This given algorithm is also supplemented by ability of shape variation for graphitic particles.

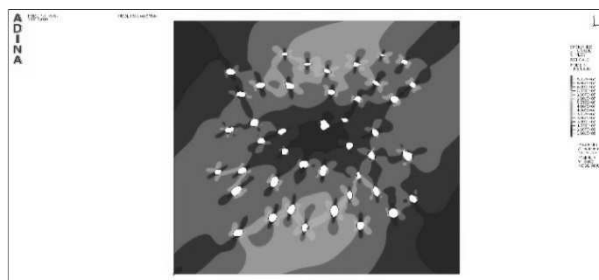
Software solution of algorithm is connected with software Octave (share-ware version of Matlab) which is able to generate input file for software GID where spline curves are used for solutions in the area relating to individual graphitic particles. End points of spline are identical but they are not continuous. The post editing of spline curves can help us to obtain continuous areas which represent graphitic particles. Subtraction of the area for graphitic particles from the whole area of investigated model is used for obtaining of resultant geometric model without graphitic particles whereby the boundaries of the model are continuous. This obtained geometric model is saved in IGES format. FEM in software ADINA is used for consecutive analysis because this software allows downloading of geometric data in IGES format. Arbitrary structure of material can be represented by graphitic particles which are randomly generated for creation of the model of various size and shape.



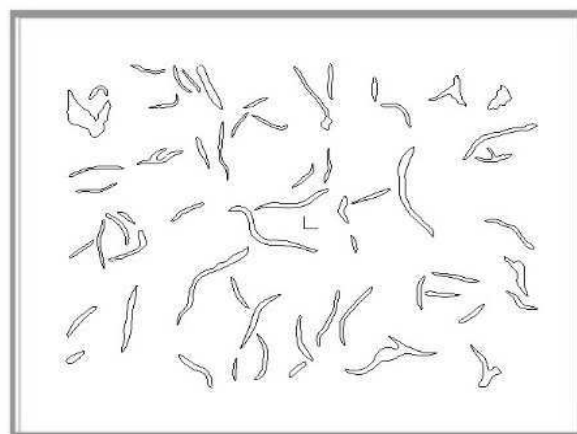
**Fig. 5** Numerical model for SGCI

As it has been said, graphitic particle can be understood as a cavity in the structure of material with its various size and shape. The whole problem is based on the solution of the two-dimensional system. The limiting conditions can be represented by taking of degrees of freedom from the whole circumference, relating to model. The linear material model with the respect to Young's modulus, also known as tensile modulus  $E = 2.1 \times 10^5$  [MPa], Poisson's ratio  $\nu = 0.3$  and mass density  $\rho = 7850$  [kg/m<sup>3</sup>] is used. The area of the resolving is determined for one or more graphitic particles with the size  $0.5 \times 0.5$  mm, while graphitic particles are generated in the area  $0.45 \times 0.45$  mm and tensile force of 1 N was used along the whole side edge of model. This chosen ratio for area

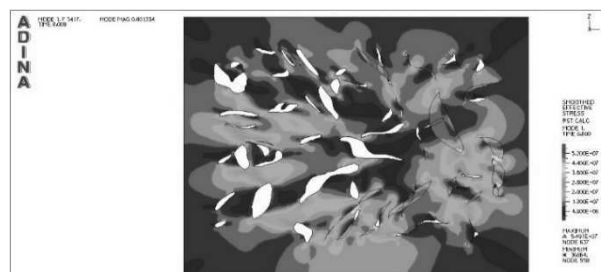
of resolution, where graphitic particles are generated, means elimination of influence including eigenfrequencies which can be connected with the closeness of boundary for area of resolution.



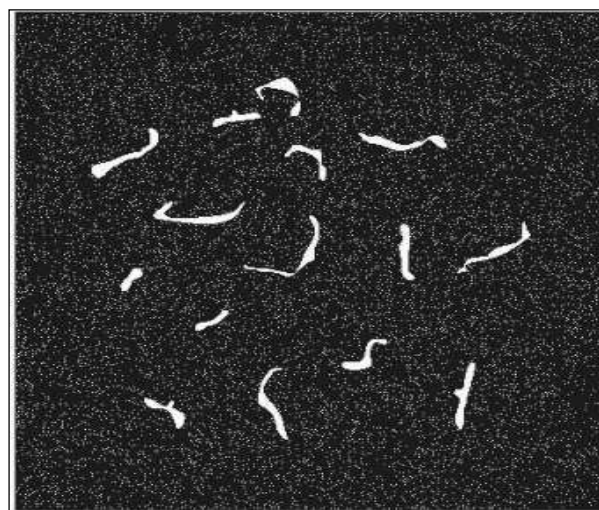
**Fig. 6** The distribution of stress around graphitic particles of SGCI



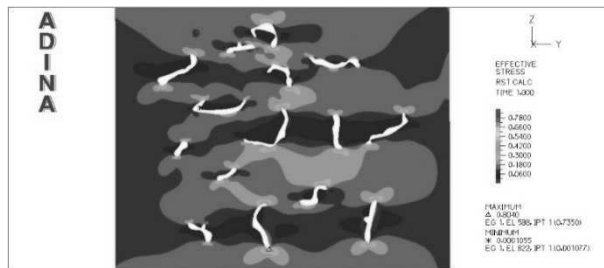
**Fig. 7** Numerical model for LGCI



**Fig. 8** The distribution of stress graphitic particles of LGCI



**Fig. 9** Numerical model for Vermicular type of graphite



**Fig. 10** The distribution of stress around graphitic particles of vermicular type of graphite

The (Fig. 6), (Fig. 8) and (Fig. 10) represent only the distribution of stress around the graphitic particles for numerical model. The algorithm for lamellar and vermicular shape of graphite was not generated because of difficult mathematical (description) formulation. The used models were formed by help of real material structures (spline curves).

## 7 Summary

Existence of graphitic particles in matrix causes concentration of stress and the intensity of the given stress depends on the shape of graphitic particles. The concentration of stress is increased by irregularity of graphitic particle. The most perfect distribution is found out for spheroidal shape relating to sphere. The mentioned process relating to investigation can be used for any other types of cast structures. The results which are obtained on the base of analyses represent the first information about loading and properties of the whole system or structure of material and the most important fact is that this given information is known.

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