Finite Element Method Application for the Determination of Hardness for Magnesium Alloys

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A numerical model was made to establish the casting hardness for the magnesium alloys MCMgAl12Zn1, MCMgAl6Zn1, MCMgAl3Zn1 and MCMgAl9Zn1. Computer simulation of hardness was performed using the finite element method in ANSYS environment, and the hardness values were obtained by experiments based on the Rockwell method. The showed model fulfils the initial criteria, which provides with the basis for the assumption about its utility in establishing the casting hardness of the magnesium alloys MCMgAl12Zn1, MCMgAl6Zn1, MCMgAl3Zn1 and MCMgAl9Zn., using the finite element method within the framework of the ANSYS program. There is the correlation of the computer simulation results with the experimental outcomes. Nowadays the computer simulation is very well known, and it is based on the finite element method, what it makes possible to better comprehend the autonomy between the process parameters and selected optimal solution. The chance of applying faster and faster calculation machines and the formation of much software enables creating the more accurate models and more the adequate ones to reality.

Keywords: Computational materials science; Finite Element Method; Magnesium alloys

It is essential in the development of modern technology to search for new constructional solutions where the major goal is to improve the effectiveness and quality of a product, and in the meantime, the minimisation of dimension and mass and also the reliability increasing and dimension stability in the operation conditions [1-5]. It has been observed for many years a rising interest in the non-ferrous metals alloys especially in those included the magnesium and aluminium alloys [6-7] which are also the part of the examination subjects in many research and at university centers in the country and abroad as well as in big producers involved in the mechanical engineering industry, chemical, power, textile, electronic, paper and aeronautic industries and in particular automotive, shipbuilding, aircraft, sports and even nuclear industries [8-15].

Broadly conceived Computer Aided Design is an inevitable part of the modern material design. It is mainly associated with the fact that computer techniques allow solving numerically numerous important and complex, in the context of calculations, technical issues in a relatively simple and rapid manner [16-22]. The technological and economic focus of production engineering requires the optimisation of the existing manufacturing processes. Computer simulation is the right tool for gaining the necessary knowledge on such processes. It, therefore, seems clear that smart prediction with the use of artificial intelligence tools is another step bringing us closer to the better exploration of the essence of research [23-33].

Due to the rapid development of computer-aided techniques, the Finite Elements Method (FEM) is currently one of an essential numerical analysis methods and is widely used in many fields of materials engineering. The computer-aided investigation of engineering materials has become a leading engineering tool due to the dynamic development of computer technologies and due to functional programmes [34-45].

The performed numerical models and computer simulations make it possible to accurately presenting the structure and to recognise the properties of the materials analysed within their whole volume.Laboratory examinations in the field of the science of metal allow, in many cases, to measure only the selected values and parameters taking into account only limited zones due to complex shapes and different properties of the tested parts' cross section.

The FEM method has also been applied for the determination of material properties such as hardness, stresses, displacements and deformations [46-55].

The work presents a model allowing the user to assess the hardness of magnesium alloys without performing experimental investigations. A comparative results analysis of the computer hardness simulation done by the Rockwell method with experimental results were accepted.

Investigation methodology and computer simulation

The hardness test was carried out with the Rockwell method subject to PN-EN ISO 6508-1:2007 standard. The method relies on the measurement of the depth of indentation made by pressing a steel ball with a diameter of 1/2 to 1/16 inch or a diamond cone (for harder materials),

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with the apex angle of 1200, into the studied materials' surface. Hardness is measured by measuring the depth of indentations using a conventional scale of hardness.

The Rockwell scale of hardness represents the depth to which an indenter is deepened permanently and determined with the formula (1):

$$HR = K - h/0.002 \quad (1)$$

where:

K - agreed on constant depending on the indenter type, which is 100 for the cone, and 130 for the ball, 0.002 mm - unit depth; for this reason, a Rockwell instrument sensor has two scales displaced relatively by 30 grids,

h – the permanent deepening of indenter after applying and removing the main load.For simulations of deformation during hardness test by Rockwell method was used ANSYS program. Taking into account that the real model is symmetric and performed in Ansys is ¼ of the real model. Maintaining appropriate edge conditions in the symmetric plane such a simplification does not impact the simulation's results whereas in considerable degree reduces the time of calculations with the help of the program. Initial loading was 98.1N and next the to whole load was 588N. The following materials data was used during simulation for casting the magnesium alloys:

-Elasticity modulus – E=50.1 GPa,

- Poissons Ratio - n= 0.3,

-Tensile Strength, Yield – Re=20 MPa,

-Tensile Strength, Ultimate– Rm=90 MPa,

- Elongation at Break – A5%=6%.

The physical model which consists of:

-Steel globule,

-Casting native material of the magnesium alloys MCMgAl12Zn1, MCMgAl6Zn1, MCMgAl3Zn1 and MCMgAl9Zn1.

The consistency of analytical model:

-Constant, undeformable and represented by steel globule,

- Contact, that shows the interaction between the steel globule and the native materials,

- The native material of casting the magnesium alloys MCMgAl12Zn1, MCMgAl6Zn1, MCMgAl3Zn1 and MCMgAl9Zn1.

The solid that shows steel globule was simulated as the undeformable constant with the help of MESH 200 element. This element is only a mesh and is not the subject of any calculations. The choice of the material for native material should guarantee the capacity for the deformation and the initial stresses. For this purpose the SOLD 95 element was used. This element is used for the three- dimensional modeling of the solid structures. It is determined by twenty knots where each of them has got the three translational degrees of freedom (UX, UY, UZ) and the properties the material (Modulus of Elasticity, Poissons Ratio, thermal condition factor, thickness). Automatically the element takes the global coordinate system. The element CONTA 174 was used to define the contact between the native material and the steel globule. This element is placed on the surface of the solid and is determined by eight knots.

Work schedule:

-The real model was performed,

-put mesh of the finite elements,

-put edge conditions,

-made the contact surface,

- loaded power to the model,

-performed calculations.

Figure 1 shows the three- dimensional view of the calculated model on which was put the finite element mesh.

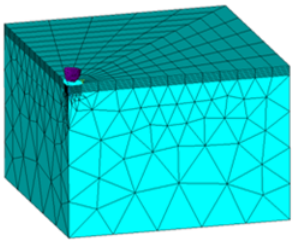

Fig. 1.The three-dimensional view of calculated model along with the steel globule and put the finite element mesh

Results and discussions

To avoid errors in calculation the different quantity of the finite elements were used. In these places, where the higher deformation of gradients was expected, the mesh is more thickened than in those places where the deformation shall have similar value. Figures 2-5 shows received results of the numerical analysis where the finite elements method was used and collected as the maps of the deformation distribution with the load and without the load a casting of the magnesium alloys MCMgAl9Zn1. Based on received results of the simulation it was possible to estimate the theoretical hardness, where the results

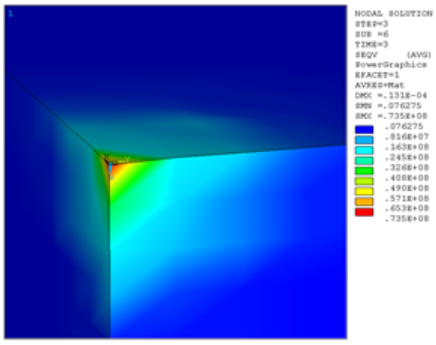

Fig. 2. State of deformed material with loading in casting the magnesium alloys MCMgAl9Zn1

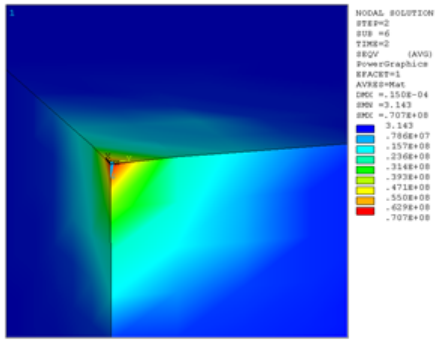

Fig. 3. Distribution of stresses with loading in casting the magnesium alloys MCMgAl9Zn1

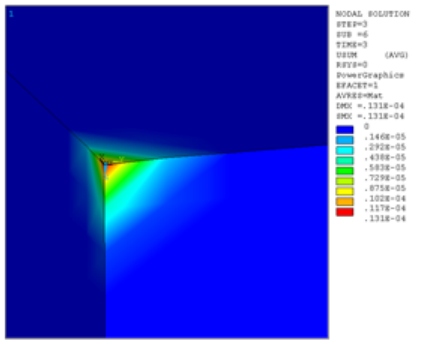

Fig. 4. State of deformed material after loading in casting of the magnesium alloys MCMgAl9Zn1

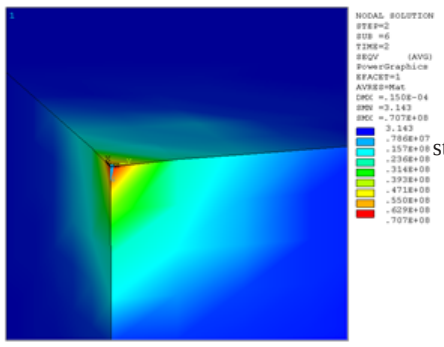

Fig. 5. The distribution of stresses after loading in casting of the magnesium alloys MCMgAl9Zn1

Hardness measurement method	Alloys MCMgAl12Zn1
Rockwell hardness tests	94.60
Computer simulations	102.3
	Alloys MCMgAl9Zn1
Rockwell hardness tests	75.14
Computer simulations	76.8
	Alloys MCMgAl6Zn1
Rockwell hardness tests	53.20
Computer simulations	58.4
	Alloys MCMgAl3Zn1
Rockwell hardness tests	31.50
Computer simulations	36.8

Table 1
THE COMPARISON OF HARDNESS RESULTS RECEIVED USING THE COMPUTER SIMULATIONS METHOD AND THE EXPERIMENTAL ROCKWELL HARDNESS TESTS FOR ANALYSED ALLOYS

correlate with the results which were received experimentally (table1).

Conclusions

The Finite Elements Method is an excellent tool for solving engineering tasks, and it is cheaper to perform a simulation than to perform laboratory tests; moreover, it greatly reduces the time of problem-solving and produces reliable results. Laboratory tests in the metal science field give, in many cases, the possibility to measure only the chosen values and the parameters within limited areas due to complex shapes and variable properties of the investigated parts' cross section. The precise data, concern the properties of the virgin material, allowed to define accurately the hardness of the magnesium alloys relative to the Rockwell hardness measurement method and establish the distribution of stresses and the occurred material deformations. The comparison of the hardness measurement results by the Rockwell method in cast magnesium alloys and in the model created in work, where the FEM method is used, and proved that the model is completely adequate with received experimental data.

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