ANALYSIS OF CRITICAL POINTS IN CONSTRUCTION OF PISTON IN ORDER TO ELIMINATE RISKS DURING APPLICATION OF THE HCCI TECHNOLOGY

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ANALÝZA KRITICKÝCH MIEST V KONŠTRUKCIÍ PIESTA S CIEĽOM ELIMINÁCIE RIZÍK PRI APLIKÁCII HCCI TECHNOLÓGIE

Abstract: *Application of the HCCI technology was till now limited due to several principal problems, such as high compression ratios and excessive heat release. Both these factors are influencing local strength of the individual constructional parts concerning the piston combustion engine, whereby the most critical constructional part is the engine piston. A casted Vertex piston was analysed with the aim to find the areas where local stress and local strength are critical for the safety. The casting technology affects the properties of the used material which was a transeutectic silumin (aluminum-base casting alloy containing about 12 at % of silicon). The critical areas are that places in the structure where the relation „local stress/local strength" reaches the maximum value. Local strength of the investigated material was estimated using a material modell based on the relation between the strength and the mean distance between dendrite arms (secondary dendrite arms spacing = SDAS) in the casted microstructure. The differencies in the strength value can reach in the casted bulk microstructure, due to local heterogeneities, up to 15%. Using the FEM analysis, Fig. 1, the stress distribution in the piston was modelled and, on the other hand, based on SDAS measuring in the casted microstructure extracted from critical areas, the local strength values were calculated for various microstructures. Based on the relation „local stress/local strength" calculated for various localities the critical places were located in the piston, Fig. 2.*

Key words: *critical places, piston, local strength, FEM*

INTRODUCTION

A failure of construction elements depends on position of a critical place and its local mechanical properties which are related to processing technology of given machine part. In the case of a casted piston of two-stroke combustion engine, the local mechanical properties are affected predominately by the casting technology. The decisive factors are especially: tension strength, critical deformation, modulus of elasticity, fatigue strength. These factors are influenced greatly by the casting method [1,2,3].

A cooling rate during casting is the most important factor with regard to material microstructure and its mechanical characteristics. An ultimate tensile strength (UTS) correlates well with the secondary dendrite arm spacing (SDAS). During the evaluation of reliability there is usually taken into consideration an assumption that the mechanical properties of material are homogenous. However, the real differences in microstructure cause a variability of mechanical characteristics in individual localities of the same material [4].

Pistons of combustion engines are made typically of the near eutectic aluminium-silicon alloys. In so far as microstructure of a cast is different in its various areas, there are also different values of mechanical properties and it is insufficient to take into consideration the mechanical characteristics of the global cast material.

One of possibilities how to determine the ultimate tensile strength is based on the secondary dendrite arm spacing (SDAS). There are well-known relations between the tensile strength and microstructure of silumins [5,6]:

$$UTS = 270 - 1.4399\ SDAS \qquad (1)$$

where: UTS - ultimate tensile strength [MPa], SDAS - secondary dendrite arm spacing [μm].

The main purpose of this work is to determine the local values of the strength by means of metallographic analysis, as well as to define the critical areas of the piston using a finite element analysis.

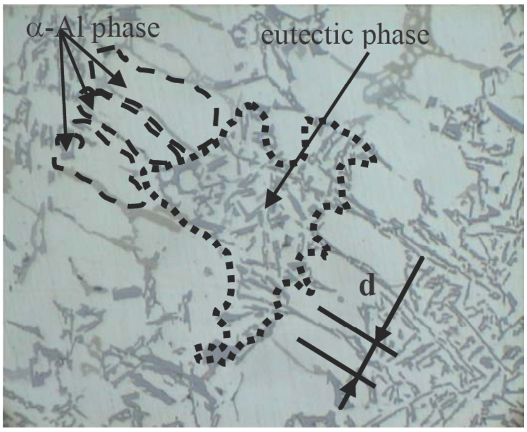
EXPERIMENTS

The gravity casted piston of the company Vertex made from near eutectic aluminium-silicon alloy was provided for this study. The piston was cut into two cross-section parts. The samples were prepared from its various areas in order to apply metallographic light microscopy which enables a statistical analysis of microstructure. The secondary dendrite arm spacing (SDAS) was measured in specific parts of the piston by identifying and measuring small groups of well-defined secondary dendrite arms on the screen of the image analyzer.

$$SDAS = d/n \qquad (2)$$

where: d - length of the line drawn from edge to edge of measured arms, n - number of dendrite arms.

The volume fractions of the constituents were quantified with an image analysis (Fig. 1) of the microstructure.

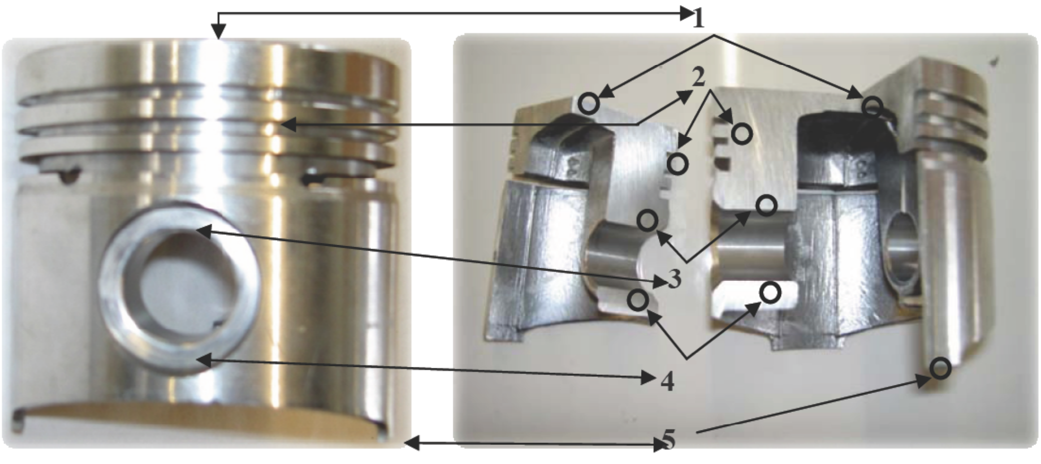


Obr. 1 *Microstructure of silumin*

The values of von Mises stress, σ_{vM}, in the selected positions of the piston by means of the FEM using the Cosmos software were determined in the next step. The material is considered to be elastic and the dimensions of analysed positions (Fig. 2) were from several hundreds μm to 1 mm in the size.

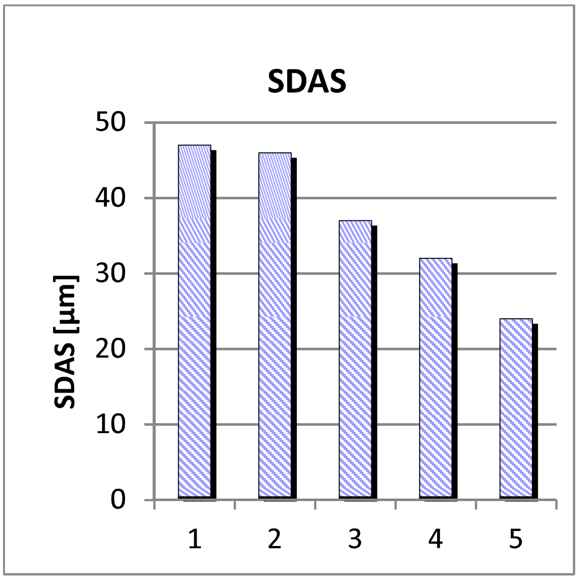
RESULTS AND MEASUREMENT

The values of the secondary dendrites arm spacing in individual areas of the microstructure are presented on Fig. 3. The difference between the minimal value (24 μm) and maximal value (47 μm) is 96 %. From a quantification of the constituent phases, Fig. 4, it is resulting that the volumetric share of eutectics increases from the position 1 (upper position) to the position 5 gradually (position of sealing flap). A supplement to the 100 % of the whole creates the dendrite α-phase.



Obr. 2 *Analysed positions in the piston: 1. upper surface (US), 2. piston rings (PR), 3. pin (P), 4. Seeger ring (SR), 5. sealing flap (SF)*

Analysing together the volume fraction of the eutectic phase with the SDAS results it is interesting to highlight the fact that exists a relation between them: the region with higher values of the SDAS has got a small amount of eutectic phase and reverse the region with the smaller values of the SDAS has got higher values of the eutectic phase.

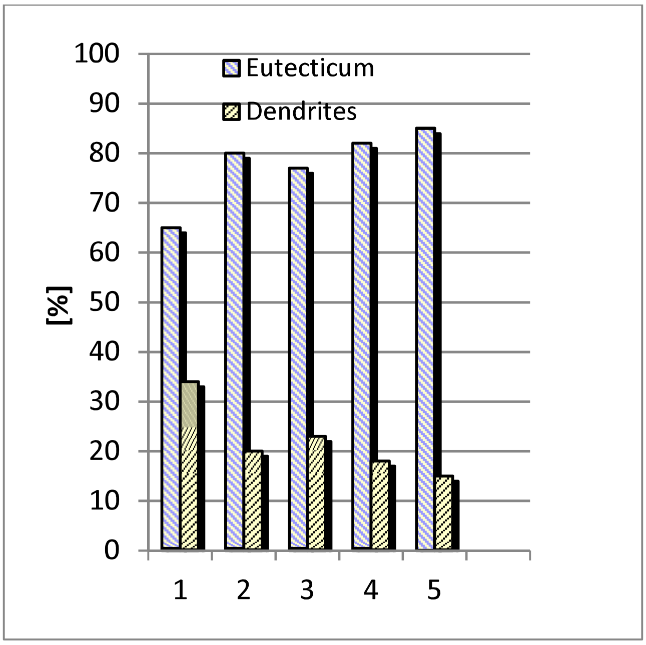


Obr. 3 *SDAS values for specific individual analysed positions*

DISCUSSION

The critical positions are such places where the ratio between the local loading stress and the local strength is the highest.

Thus, estimative prediction of the cast aluminium component properties should be made based on local material mechanical properties, which enables to calculate the ratio of stress vs. ultimate tensile strength. Local mechanical properties may be obtained by local metallographic analysis.



Obr. 4 *Quantification of constituent phases*

The ultimate tensile strength UTS_{SDAS} was then calculated from experimentally determined values of SDAS according relation (1) in all specific positions 1-5. The results of microstructure evaluation (SDAS) and local strength value UTS_{SDAS} are presented in the Tab. I. It can be seen that there is a change in SDAS of about 100%, as occurs between positions 5 and 1, and that it is equivalent to significant changes in UTS, e.g. the stress level changes from about 236 to 202 MPa (about 17 %).

Analysis of the loaded piston stress state, Fig. 5, using the FEM [5] proved that there are predominately two important critical areas with regard to the stress state: the upper holes of the piston pin (3) and the piston head (1) with the piston rings (2), Fig. 6. The stress values for each of the piston position (Fig. 2) are obtained by means of the FEM, $_{FEM}$, Tab. I.

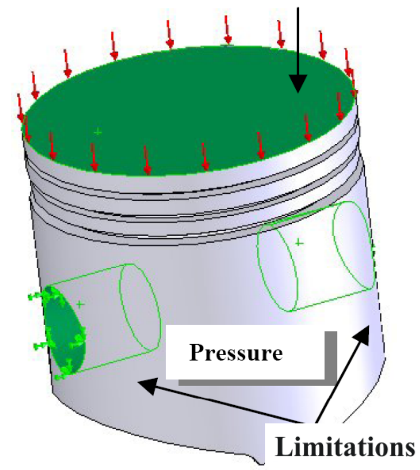
A global design uses only one material value for the whole component, e.g the UTS=236 MPa for those microstructure with the highest strength.

Tab. 1 *Measured and calculated values of SDAS and load for different positions in the piston*

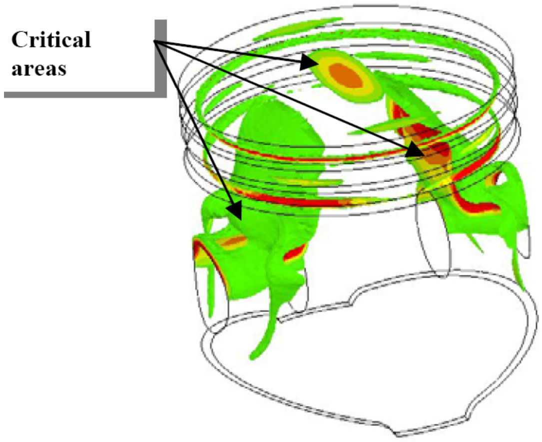
Position	**SDAS [µm]**	**UTS_{SDAS} [MPa]**	**σ_{FEM} [MPa]**	**σ_{FEM} / $UTS_{SDAS,max}$ global**	**σ_{FEM} / UTS_{SDAS} local**	**local-global [%]**
1 upper surface	47.0	202	56	0.237	0.277	16.7
2 piston rings	45.6	204	78.4	0.332	0.384	15.6
3 pin	37.9	215	96	0.407	0.446	9.6
4 Seeger ring	31.5	225	44	0.186	0.196	5.1
5 sealing flap	23.6	236	21.2	0.080	0.090	0.1

The corresponding relative load σ_{FEM} / $UTS_{SDAS,max}$ is in the 4rd column in the Tab. I. These values are different from those obtained by means of a local approach. In this case the values of the stress σ_{FEM} obtained by the FEM are related to the real ultimate tensile stress values UTS_{SDAS} (as obtained by the metallographic way based on the SDAS) in different positions of the component, σ_{FEM}/UTS_{SDAS}, Tab. I, 5th column. The difference between local and global approach can reach the maximum difference of about 16.7 %.

These differences can be relevant mainly in the case of fatigue loading, in this case also changes of positions of the critical areas can be expected.



Obr. 5 *Pressures and limitations applied on piston surfaces*



Obr. 6 *Stress distribution in critical positions*

CONCLUSIONS

The values of local strength were determined in selected specific positions of piston casted from the silumin alloy based on relation between UTS and microstructure parameter SDAS. The difference between local and global approach reach up to 17 % for selected positions of the whole component. To ignore the real local load can cause an early failure of component.

The study analyses the critical positions in the combustion engine pistons produced by gravity casting of near eutectic aluminium-silicon alloys. The local strength in various positions was calculated from secondary dendrite arm spacing in the microstructure, the real local load was calculated via finite element analysis. The global strength approach uses one strength value for the whole component, while the local approach uses the local strength values depending on local microstructure. The difference between both local and global strength approach can reach up to 17 %.

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