V-CAT based computation of the elastic properties of the porous cast aluminum

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Abstract:

Casting is one of the most popular process for manufacturing complex parts. However, during casting different porosities occur in the casted parts, mostly produced by the trapped gases and shrinkage. One example of such a part is the engine block. For lightweightening purpose, currently block engines are manufacturing through casting of aluminum alloys. CT scans analysis of the block engines shown a certain porosity which is unevenly distributed. During the use of the block engine, these pores will be undergone to cyclic loadings which lead to propagation of the porosity as crack and eventually creating coalescences of these pores. These coalescences lead to complete failure of the structure. Considering these aspects of the cast parts, it is reveal the importance of characterization of the porosity after casting and determination of its impact on the elastic properties, namely two elastic constants: Young modulus and Poisson ratio.

The paper proposes an algorithm for determination of the impact of the pores on elastic properties on a cast structure of an AIS4 aluminum alloy used in a Toyota block engine. The algorithm involves serial sectioning of probes cut from a cast part, tridimensional (3D) reconstruction of the pores as well as positioning them in the probe. 3D reconstruction of the porosity is done aided by an in-house software - V-CAT. V-CAT is a volume segmentation software which extracts the target regions of 3D image data obtained by imaging devices such as X-ray CT, MRI, and confocal laser scanning microscopy (BMP and TIFF formats consist of cross-sectional images). It is also equipped with a function for creating surface meshes from segmented images (VOBJ, STL). Further, the object obtained through 3D reconstruction in V-CAT is meshed with solid volume elements. The representative volumes obtained from different areas of the probes are modeled in finite element under a set of loadings: tension, compression, pure shear, shear and bulk compression. The compliance matrix is calculated and based on the results of these tests. Thus, the numerically identified elastic behaviour allows to identify the 9 unknowns of the anisotropic elastic moduli, $C_{11}...C_{66}, C_{12}, C_{13}, C_{23}$. From the anisotropic elastic moduli, it is necessary to identify the equivalent (or so-called effective) isotropic elastic constants. The minimization of cost function allows to identify the effective elastic constants for a given porosity of the volume element. Based on the obtained values, the elastic modulus – porosity on one hand and Poisson ratio – porosity relationships are identified.

The homogenization technique allowed the identification of both the elastic constants for a given porosity and the evolution laws for the elastic constants. Mapping the real porosity as a state variable in a uniform finite element mesh shall contribute to an optimized design of cast products. Comparison between "porous" and uniform results under well-defined loading paths seems demonstrate the validity and interest of the proposed numerical procedure.

Key-words: porosity of the casting processes, 3D reconstruction of pores, elastic constants

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