Functionally graded materials and structures

A genuine novel optimization approach for FGM axisymmetric bodies

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Functionally graded materials (FGMs) are a kind of composite materials, whose physical and mechanical properties vary spatially along specific directions over the entire domain [1]. Unlike conventional homogeneous materials, the spatial variation of mechanical and physical properties in FGMs can be exploited to obtain better performances by microstructural control. The optimum response of material properties to an actual environment is the main requirement in the design of FGMs, nevertheless few works deal with the problem of optimal material distribution because, often, the optimization process considerably relies on subsequent Finite Element forecasts. In addition, in the works available in the literature, finding the solution of an optimization problem usually consists in determining the values of some tuning parameters of the grading indices for prefixed classes of property variations, such that an objective function is minimized, e.g. [2,3]. We believe that an intrinsic, genuine and more realistic optimization problem should a priori consist in the search for property variations and not merely the tuning values belonging to prefixed property distributions. The resulting optimization framework is both suitable for practical aspects associated with the manufacture process – since optimal solutions are in terms of the constituents' volume fractions – and novel from the theoretical viewpoint – being applicable regardless of the involved micromechanical model. In this paper we address the problem of finding the optimal composition profile of the constituents for axisymmetric thin bodies subject to mechanical loadings. The material is assumed to be functionally graded in the radial direction. In light of these considerations, the plane theory of elasticity holds and equilibrium, compatibility and constitutive relations are recalled. Different optimization problems are then formulated and analytically solved in the context of optimal control theory. Finally, hints on the computational details of the solution are addressed. [1] Miyamoto, Y., Kaysser, W.A. & Rabin, B.H. Functionally graded materials: design processing and applications. Kluwer Academic Publishers, London, 1999. [2] Abdalla, H.M.A., Casagrande, D. & Moro, L. (2020). Themo-mechanical analysis and optimization of functionally graded rotating disks. Journal of Strain Analysis for Engineering Design. DOI: 10.1177/0309324720904793journals.sagepub.com/home/sdj [3] Khorsand, M. & Tang, Y. (2018). Design functionally graded rotating disks under thermoelastic loads: weight optimization. International Journal of Pressure Vessels and Piping 161: 33–40.

Numerical Investigation on Effective Toughening Mechanisms of Graded Composites

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Graded composites, also known as functionally graded materials (FGMs), are referred to the class of materials possessing space-varying properties in different dimensions. Such material formations commonly present in various biological/natural objects, such as human/animal bones, teeth, and organs, to conveniently comply with various objectives/functions at different locations. In today's engineering society, vital structural components are manufactured by mimicking this phenomenon in order to achieve the desired toughness and responses at different crucial usage regions. Thus, it is highly important to manufacture these parts with higher toughness and lower cost. In this study, an ordinary state-based peridynamic (OSB-PD) model is purposed to enhance the toughness and decrease the material cost of such structural components having complex material zones. To account for complexity of the FGMs in OSB-PD analysis, different averaging techniques including simple, moving, and weighted averaging models are used to determine the OSB parameters of the bonds between the points with different characteristics. A comparison of these averaging techniques is carried out by solving the complex benchmark problem for mixed mode I-II fracture loading condition. The OSB model in this paper is further developed to assess the various challenging effects including the toughness enhancement of the micro and macro internal features in FGMs. For this purpose, we have solved numerous example

problems and demonstrated the enhanced toughening effects of features such as micro-cracks, holes, and strengthened/weakened material subdivisions. To evaluate the toughening effect of different features, the total rupture length is taken as the basis of comparison. It is demonstrated that the overall toughness of FGMs can highly be enhanced by precisely embedding the proposed combinations of internal features. Overall, a comprehensive fracture modelling and toughness enhancement of FGMs with various micro and/or macro discontinuities and different material sub-regions are achieved using the novel OSB-PD approach.

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Functionally graded Ti(C,N) coatings and their production on titanium using solid carburizing associated with induction heat treatment

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There are many ways to improve the mechanical characteristics of titanium items using various methods of coating deposition. They include oxidation, gas-thermal spraying, PVD and CVD techniques. These methods have disadvantages, i.e. the resulting coatings are characterized by low hardness and brittle fracture resistance combined with high porosity and morphological heterogeneity, and the processes themselves are energy-consuming and not resource-saving. The urgency of the work lies in the absence of new effective approaches to improving the mechanical properties of titanium items in various friction pairs. For this reason, it is proposed to perform resource-saving solid carburizing associated with induction heat treatment (SC-IHT) in order to strengthen the surface and increase its wear life. The aim of the work is to develop a technology for the production of wear-resistant coatings of carbide and nitride composition on the titanium surface of the working parts of equipment, e.g. converters of flaw detection devices. Titanium samples were subjected to machining and ultrasonic cleaning in ethanol. The surface of the prepared samples was treated using solid carburizing. The prepared samples were placed in a refractory container and coated on all sides with a finely dispersed carbon-containing medium (graphite). The SC-IHT comprised intensive heating up to the required temperature, exposition at the quasi-stationary temperature, and subsequent cooling. As a result of this hard coatings were formed. The SC-IHT effect in the temperature range of 1100–1400 °C on the performance of micro- and nanostructure of the coatings and mechanical properties was defined. Modes selected for the coating production on the samples were assigned to double numbers: the first number corresponded to the temperature of the surface of refractory container, the second one indicated the treatment duration measured in seconds. The chemical composition of the coated samples was studied by EDX analysis, which was performed with scanning electron microscopy. The hardness of the samples with coatings was evaluated using the Rockwell and Vickers methods. During micro- and nanoindentation, a mechanical properties tester was used. The temperature field inside a refractory container with a titanium sample was determined. For this purpose finite element modeling using the "Elcut" software (the version of the "QuickField") was used. The obtained temperature values ensured the necessary chemical reactions between titanium and solid-gas medium (carbon and nitrogen), which was confirmed by phase diagrams. All obtained samples with functionally graded Ti(C,N) coatings had in their composition the main component of the substrate – titanium, the main component of the reaction medium was carbon, and nitrogen admixture, which was preserved from the atmosphere. The composition of the coatings at a minimum SC-IHT temperature of 1050–1100 °C and a process duration of 240–480 s corresponded to the carbide-nitride (TiC0.14–0.25N0.75–0.86) system. In the temperature range 1250–1400 °C, the composition of the coatings was stabilized by Ti0.32–0.37N0.63–0.68 system; however, the mechanical properties had significant differences. The microhardness H of Ti(C,N) coatings depended on the temperature T and duration t of the SC-IHT in the graphite medium. A minimum H of 10–12 GPa was observed at T = 1050–1100 °C. With an increase in temperature to T = 1250–1300 °C, the hardness grew as well reaching a maximum of about 20 GPa. In the study, the nanohardness was 47.6±12.9 GPa, which corresponded to the production of a superhard layer combined with high plasticity index of 0.16 and brittle fracture resistance of 1.28 GPa. Thus, the resulting system has a gradient of mechanical properties and it can be used under conditions of shearing and abrasion by hard fragments