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Production method of rubber and sulfur FG composites

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Abstract

In the presented work, sulfur concrete and rubber were used for producing functionally graded materials (FGM). The physical and mechanical properties of sulfur concrete and rubber were changed continuously across the thickness. On one side, there was just rubber and, on the other, there was pure sulfur; the properties of each substance were moved to reach another. This kind of material was constructed by applying mechanical pressure on all layers together and heating in a casting die. Thus, it is essential to consider the quantity of sulfur and rubber at each layer and the rule obeyed by physical and mechanical properties. In the drop test, it was found that the elastic impact coefficient changed from sulfur concrete around 50% to rubber around near zero. It seems that, by changing some parameters like combination percentage or layers' thickness, it is possible to optimize the FGM.

1. Introduction

Functionally graded materials (FGMs) are now so applicable in many structures with different objectives including nuclear plants and spacecraft. Using all the properties of these materials simultaneously in the functionally graded form leads to producing multi objective materials. The main application of this work is in offshore engineering such as in harbours and oil rigs. When ships get near the ocean structures, flexibility and resistance to the surface corrosion is so useful, like in rubber; however, for coating these structures, a tough surface is needed like sulfur concrete. In addition, functionally graded material consists of sulfur concrete and rubber is so applicable for coating some structures in water. Rubber is posed to impact and tension and these loads pass through thickness and damp on the sulfur concrete side. In FGMs, the properties can be functionally changed by combining two materials; also, these prosperities depend on material, and function depends on the mixing routine.

Kashtalyan and Menshykova [1] analysed an FGM coating/substrate system of finite thickness subjected to transverse loading. The Young's modulus of the coating was assumed to vary exponentially through thickness. A comparative study of FGM versus homogeneous coating was conducted by Stewart et al. [2] reported the rolling contact fatigue (RCF) analysis of functionally graded

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WC–NiCrBSi coatings deposited by a JP5000 system and subjected to post-treatment. Choy and Felix [3] presented various functionally graded diamond-like carbon (DLC) coatings which were developed for improving the coating adhesion of DLC onto 304 stainless steel and Ti–6Al–4V substrates.

Liu and Wang [4] considered the elastostatic problem related to the axisymmetric rotation of a rigid circular punch which was bonded to the surface of a functionally graded coating with arbitrarily varying shear modulus on a homogeneous half-space. The graded coating was modeled as a linear multi-layered medium using the transfer matrix method and Hankel transform technique. Aboudi et al. [5] provided a theory of the full generalization of a new Cartesian-coordinate-based higher order theory for functionally graded materials using the standard micromechanical approach based on the concept of a representative volume element, commonly employed in the analysis of functionally graded composites by explicitly coupling the local (microstructural) and global (macrostructural) responses.

Cannillo et al. [6] presented the method for producing Glass–alumina functionally graded materials in two different methods. The first method was percolation, which was representative of natural transport-based processes, and plasma spraying, which was representative of constructive processes. Mohammadi et al. [7] presented the application of sulfur pipe in sewage pipes, methods of producing these pipes and their comparison. A hot mixture of sulfur and aggregate was provided and used in three methods for this purpose. The first one was casting method, the second Brazing method and the third centrifugal casting. Mohazzab et al. [8] studied the analytical solution of one-dimensional stresses for a hollow cylinder made of functionally graded material with heat source. Material properties varied continuously across thickness according to power functions of radial direction. The thermal boundary conditions might include conduction, flux and convection for inside or outside of hollow cylinder.

Mohammadi et al. [9] presented the analytical solution of one-dimentional stresses for a hollow sphere made of FGM with heat source. The material properties vary continuously across the thickness, according to power function of radial direction. The thermal boundary conditions may include conduction, flux and convection for inside or outside of hollow sphere. Mohammadi et al. [10] presented the magnetic problem of functionally graded hollow cylinder subjected to mechanical and thermal loads using the infinitesimal theory of magneto-thermoelasticity. The material properties and magnetic permeability varied gradually across the thickness direction according to power functions of radial direction.

Mazare et al. [11] presented an incremental melting and solidification process (IMSP) which was used to obtain components with controlled gradient in chemical composition along one direction of the piece. The composition variation was externally induced by a sequential addition of different materials. Li et al. [12] produced the new material by joining Yittria Stabilized Zirconia (YSZ) to Ni–20Cr (NiCr) using YSZ–NiCr functionally graded materials' (FGM) interlayer through hot pressing process. Microscopic observations indicated that the graded distribution of the composition and microstructure in the joint eliminated the macroscopic ceramic/metal interface. Han et al. [13] developed functionally graded SiAlON ceramics to improve the mechanical properties of SiAlONs by three different methods: powder bed, rapid cooling and laminating.

Dahan et al. [14] studied functionally graded transition zone between a hard TiC coating and a WC–Co substrate, e.g. a cutting tool, which could be formed over the range composition of the titanium carbide phase that extended from Ti_2C to TiC. The transition zone was formed by sputter deposition of a multilayer stack of nanometric TiC and Ti layers. The composition gradient within the carbide layer was generated by varying the relative thickness of as-deposited Ti and TiC layers. Movchan [15] investigated electron beam evaporation from one source of multicomponent mixtures of metallic and non-metallic materials, which was prepared in the form of compacted tablets or composite ingots.

Jung and Choi [16] studied three mole percent Y_2O_3 doped tetragonal zirconia polycrystals (TZP) and stainless steel 304 (SUS) functionally graded materials (FGM) were fabricated by slip casting. To overcome the problems of the gypsum mold (GM) in the slip casting process, an alumina mold (AM) was prepared and its properties were investigated after controlling the microstructure and sintering conditions. Gao and Wang [17] numerically investigated the solidification process during centrifugal casting of functionally graded materials (FGMs), with a focus on the interplay between the freezing front propagation and particle migration. Considering the particle transport, a one-dimensional solidification model was developed based on the general multiphase model.

One of the known functional materials is the mixture of metal and ceramic. Metal has high fracture toughness and ceramic is heat resistant and erosiive and corrosion resistant. It is useful for some vehicles which are posed to high temperature such as spacecraft and some industrial ones such as nuclear plants. Figure 1 illustrates the mixing procedure, in which, from the bottom of the figure, metal decreased gradually and ceramic increased until getting pure at the top [18].

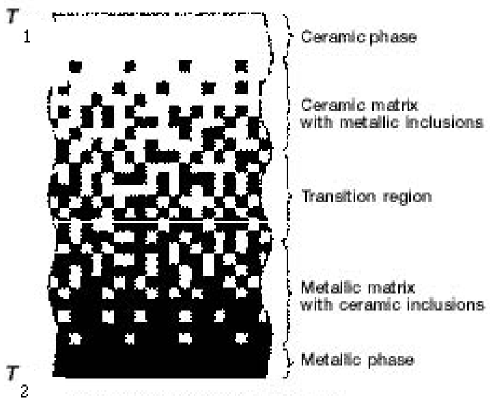


Fig. 1. Mixing procedure [18].

In this paper, one kind of composite was manufactured in which the material properties functionally changed through thickness for some purposes. In this study and in a new method, sulfur concrete, rubber compound and flexibility were important on the one side and toughness on the other. The compression and drop tests were presented.

2. Methodology

Sulfur concrete consists of sand and sulfur which is heated by 150^{o}c; after some hours, it reaches the ultimate strength and has ACI standard as well. This kind of concrete has many advantageous such as being corrosion resistant and water proof and omitting water from the producing procedure and upper strength. This material is a thermoplastic which gets to the maximum nominal strength of about 7000 (lb/in^2) after being heating at 138^{o}C passage of some hours. But, sulfur concrete is brittle and can be damaged and lead to crack under some environmental pressure.

For preventing from the existing crack, it is useful to apply ductile material like rubber for decreasing brittleness. Rubber has low modulus elasticity and is used in some tubes, for transferring water, or in belts. It is heat, corrosion and erosion resistant and also is resistant to chemical factors and is used in tank military body. Rubbers are divided into two categories of natural rubber, which has lower modulus elasticity and is resistant to cutting, and artificial rubber, which is resistant to corrosion.

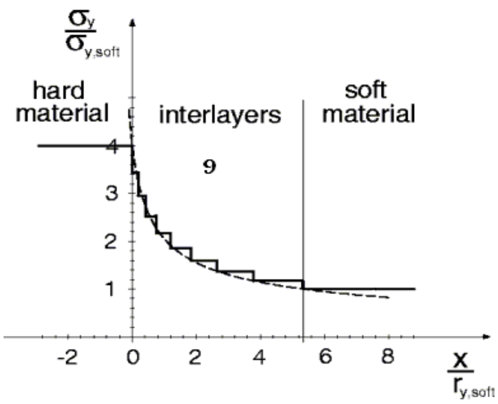


Fig. 2. Strength distribution in layers [5].

Figure 2 illustrates strength distribution from hard material to soft material [5]. As can be seen, in inter layers mechanical gradually and smoothly changed. Modulus elasticity for soft and hard rubbers was from 500 to 5000 (lb/in^2) and its heating limitation was around 180^o F.

Sulfur had the following major prosperities:

- Atomic mass 32
- Density 2.06 gram/cm3
- High strength
- High rigidity
- COR (coefficient of restitution) of near 60%

And rubber prosperities included:

- COR of near zero
- Low strength
- Softness
- Excellent shock and impact absorption

(a)

(b)

Fig. 3. Sulfur concrete (a) rubber (b) powder.

3. Experimental method

This functionally graded sulfur concrete-rubber consisted of eleven layers with different percentage in each. Figure 3 shows the sulfur concrete and rubber powders. Figure 4 demonstrated the layers with different sulfur concrete and rubber. At first layer on the top right side, there was just rubber without sulfur concrete and, at last layer on bottom left side, there was just sulfur concrete without rubber. As can be observed, at inter-layers, the quantities of rubber decreased and sulfur concrete increased gradually. Using casting die for producing the procedure is given in Fig. 5. After providing the layers, they were put into casting die, heated up to near 110^{o}c, the screws of cast were gradually tightened and the layers were compressed as hard as possible. With this procedure, an FGM material with 11 layers was produced. It was essential to do some tests, one of which was compression test for investigating and measuring strength which was done in Amirkabir University of Technology's laboratory. Figure 6 shows the concrete compression test.

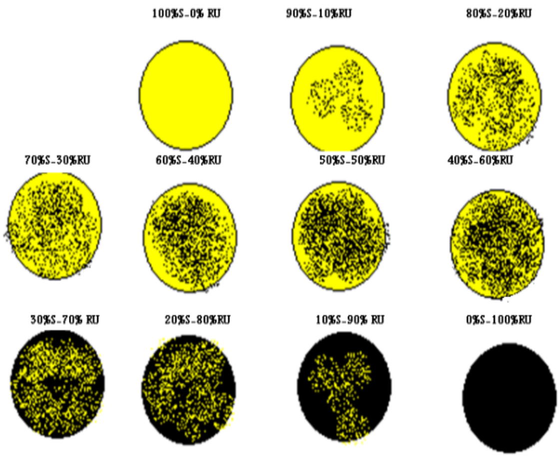


Fig. 4. Powders mixing plan.

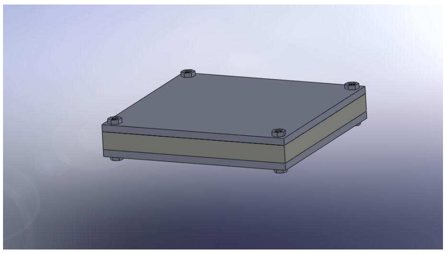


Fig. 5. Casting die.

Fig. 6. Sulfur concrete compression test.

The second test and the main test is drop test for evaluating the coefficient of restitution (COR). This test was performed manually using a 100 cm scale and a standard ping pong ball. Equation 1 was used for calculating the COR, which showed elastic impact coefficient as:

$$C_R = \frac{V_2}{V_1} \quad (1)$$

where V_1 is the scalar of initial velocity of the object before impact and V_2 is the scalar of final velocity of the object after impact. Equation 2 also could be shown as:

$$C_R = \sqrt{\frac{h}{H}} \quad (2)$$

where h is the bounce height and H is the drop height.

4. Results and discussion

At first, the 5×5×5 cm^3 specimen of sulfur concrete was considered for compression test and, after that, this test was done on the functionally graded sulfur concrete and rubber and the results were surveyed.

As observed in Fig. 7, with increasing the force which was applied on pure sulfur concrete specimen, the ultimate stress increased. Figure 7 and Table 1 show compression test for pure sulfur concrete, in which pure sulfur concrete failed between 12000N and 14000N. And also, it should be noted that, in Fig. 8 similar to Fig. 7, with the increase of force for FG sulfur concrete and rubber by 50% combination, the ultimate stress increased.

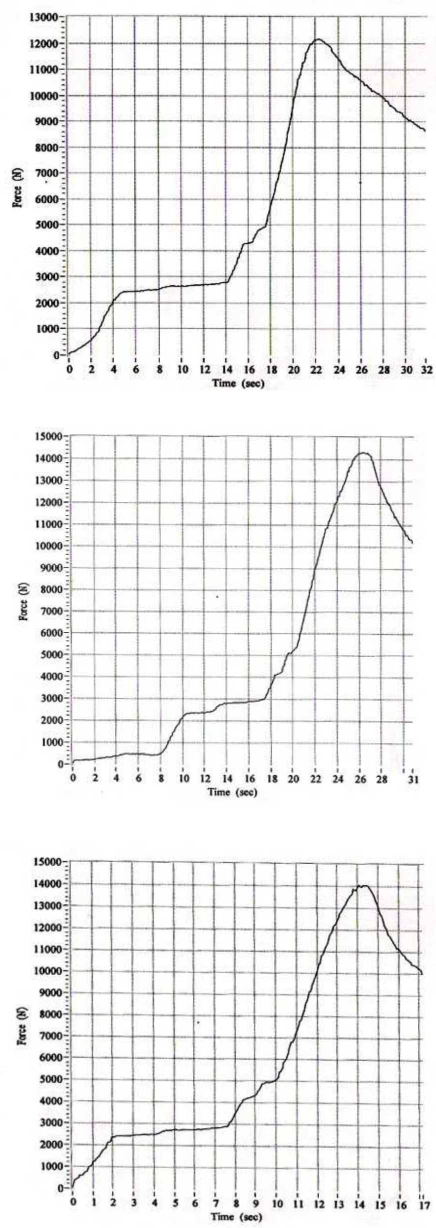


Fig. 7. Compression test for pure sulfur concrete (force versus time).

Figure 8 and Table 2 demonstrate drop test results for FG sulfur concrete and rubber. Like the second test, when percentage of sulfur concrete in the functionally graded material gradually decreased, the COR decreased and ability for the impact absorption increased.

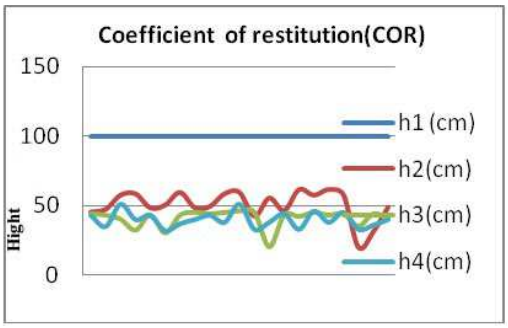
Figure 9 shows variation of elastic impact coefficient versus increasing the rubber in FGM. With this graph, it is easy to determine what kinds of FG can satisfy considered purpose and can optimize FG according to each application with increasing or decreasing rubber.

Table 1. Results of the compression test for pure sulfur concrete.

Row	Code	Ultimate Force(Kg)	Ultimate Stress(bar)
1	41	9196	368
2	42	9630	386
3	43	9902	396

Table 2. Results of the compression test for sulfur concrete and rubber by 50% combination.

Row	Weight (g)	Ultimate Force(Kg)	Ultimate Stress(bar)
1	220	1240	50
2	210	1460	58
3	212	1434	57



h1: 100 cm first height for falling ball
h2: for 100% S
h3: for 90% S – 10% RU
h4: for 80% S – 20%RU

Fig. 8. Drop tests for FG sulfur concrete and rubber.

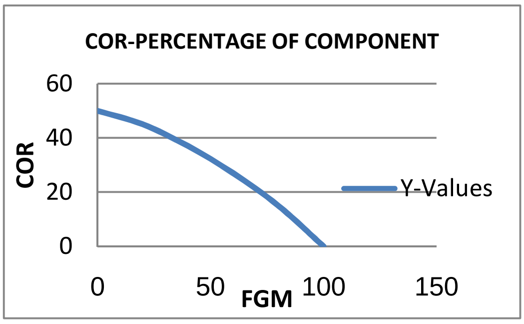


Fig. 9. Variation of COR versus combination of FGM.

5. Conclusions

In this paper, stages and procedure of manufacturing the functionally graded sulfur concrete and rubber were studied. In concrete basements, both strength and elastic behaviors were so important. By adding different percentage of rubber powder into sulfur concrete, the coefficient of restitution changed, which led to changing elastic behavior of the structure. By making a sandwich panel with eleven layers of sulfur concrete and rubber powder, variation of COR changed from 50% for pure sulfur concrete to near zero for pure rubber. Decrease of compression ultimate stress from sulfur concrete around 380 bar to rubber around 30 bar was significant. It should be noted that, with changing some parameters such as percentage of gradient of FGM or thickness layers, FGM can be optimized. This result is useful foroffshore engineering and platform coating; when the carriage impacts the sulfur concrete structures, it causes some defects for both carriage and structures. By increasing the percentage of COR, it is possible to decrease damage.

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