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Mechanical Properties of Metal- and Ceramic-Polymer Composites Formed via Thermal Spray Consolidation—Extended Abstract*

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Polymeric composites, with either metallic or ceramic fillers, have been manufactured by thermal spray, and their mechanical properties have been measured. The advantage of this technology is that it allows on-site manufacture and is a repairable composite system, with virtually no cure time and no release of volatile organic compounds. Fracture mechanisms have been studied to examine mechanical modeling of the composite system.

Keywords mechanical properties, polymer-ceramic composites, polymer-metal composites, thermal spraying

1. Introduction

This work has been carried out for applications that require a reduction in mechanical wear and/or to confer upon a polymeric deposit a certain functional property through the introduction of value-added powder.

The effects of the filler content on the mechanical properties (i.e., secant modulus, yield stress, tensile strength, elongation to break, and energy to break) are reported and discussed.

2. Experimental

Ethylene methacrylic acid copolymer powder was manufactured by PFS Thermoplastics (Big Spring, TX) and referenced as PF111. Cryogenically ground, the powder is of irregular shape with an average size of 115 μm. Nickel-chromium (NiCr) alloy powder of ~23 μm particle size, and alumina (Al_2O_3) of ~16 μm were thoroughly mixed with the polymer and employed as feedstock for the combustion spray process. The NiCr and Al_2O_3 powders had spherical morphologies.

The Powder Pistol 124 PFS (Thermoplastic Powder Coatings, Big Spring, TX) uses a propane/air mixture as the combustion gas and was connected to a Tecflo 5102 powder feeder (Thermoplastic Powder Coatings, Big Spring, TX) to spray the coatings. The spray parameters were regulated to produce efficient polymer melting without any effect on the filler. Compressed air was used for powder transport carrying the blend through the flame and allowing the polymer particles to impinge upon the substrate in a semi-molten state. Continuing the process allows the thermoplastic powder to fully coalesce and leads to a composite coating with filler distributed within the polymer matrix. The composite coatings were sprayed to approximately 2 mm in thickness and removed from a Teflon-coated substrate when cooled to room temperature.

In order to minimize edge flaws, which can arise from cutting, a stamp tool was used to produce reproducible ASTM D 632 type IV dog-bones. Tensile testing was conducted on a system manufactured by Applied Test Systems (ATS). Strain rates of 50 mm/min were used in this study.

3. Results and Discussion

3.1 Spray Deposition Efficiency

The method of using blended powders as the feedstock allowed composites with a maximum of ~11 vol% ceramic and 32 vol% metal to be manufactured. The efficiency could be further improved by using composite forms of the duel component feedstock (Ref 1).

3.2 Tensile Properties

The representation of the tensile properties is represented as a function of the filler content (vol%) and plotted in Fig. 1 to 3.

Figure 1 shows the variation of the relative modulus E/E_1 with respect to the volume fraction of filler for the metal and the ceramic additives. The polynomial growth of these curves indicates how the filler influences the composite stiffness. Since the particle morphology for both feedstock powders are similar, the different behavior may be attributed to the distinct filler/polymer modulus ratio and/or a more efficient load transfer between

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the filler and polymer. The Al_2O_3 phase confers a greater increase in modulus in comparison to NiCr.

Figure 2 displays the variation of the relative tensile strength σ/σ_1. The behavior is the same for both materials up to the maximum Al_2O_3 content. At this point the relative strength at ~11 vol% NiCr changes and appears to rise. Less polymeric material is available to strain harden, and a greater amount of load is transferred to the NiCr phase.

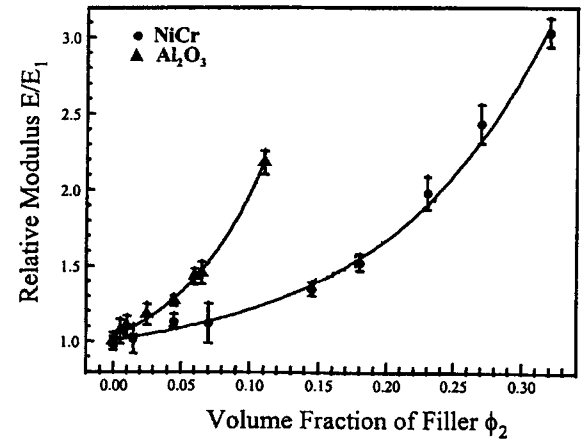

Fig. 1 Relative modulus as a function of filler content (vol%)

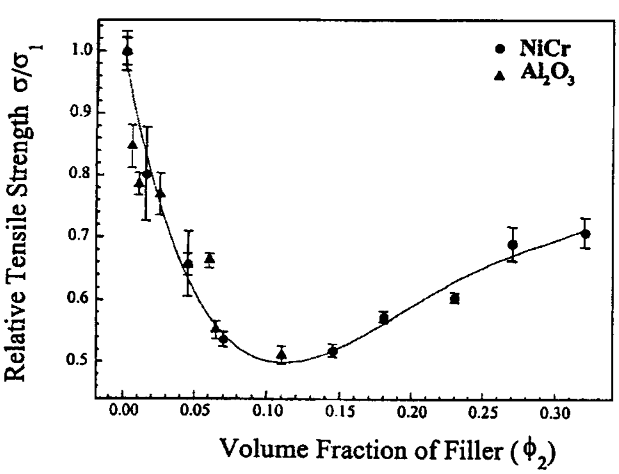

Fig. 2 Relative tensile strength with respect to filler content

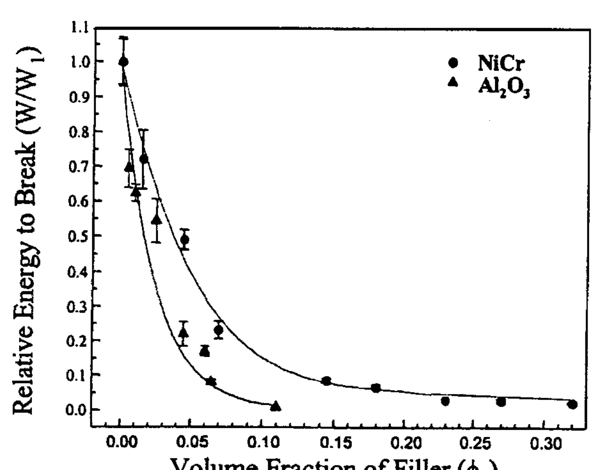

Fig. 3 Relative energy to break with respect to filler content

3.3 Toughness Properties

Figure 3 shows the variation of the relative energy to break, W/W_1. The toughness (as defined by the integrated area under the stress strain curve) decreases exponentially with increasing filler content. The energy to break decreases since the actual elongation experienced by the matrix is greater than the measured elongation of the specimen (Ref 2). Although this is a composite structure, all the elongation is in the matrix phase since the filler is rigid. The fit for the metal polymer composite can be approximated by two straight lines that meet at ~10 vol% NiCr.

4. Fracture Mechanisms

4.1 Low Filler Amounts

During the early stages of sample deformation at low amounts of filler and prior to yield, the tensile stress is distributed in the polymer and induces stress concentration at weaker points. The axially applied stress is particularly intense in the radial interface between the rigid particle and softer polymeric matrix. Thus, the polymer undergoes dilatation that leads to debonding at both ends of the spherical particulates (Ref 3). Microvoids and cavities are created and grow in the stress direction in a dewetting process (Ref 2). After the yield point, strain hardening can still take place because stretching of the polymer fibrils does not interfere with the filler. The higher the filler volume fraction is, the greater the disturbance.

The second and critical stage is induced by a change in the stress concentration that is transferred at the equator of the particles. Cracks may be generated that act as a network of weak links throughout the composite structure. The observation of a lower ultimate stress needed to break the sample is due to a reduction of the polymer fraction.

4.2 High Filler Amounts

At greater filler content, the initial stress field is displayed in the matrix and absorbed preferentially at weak points. More stress is required to start the debonding because the load transfer to the particles is greater; that is, the composite strength increases. Thereafter, the small distance between the particulates allows cracks to form, and brittle fracture occurs. Nevertheless, the strain hardening phenomenon of the polymer is more significant than the capability of the particles for the materials studied to absorb energy.

5. Conclusions

Polymeric composite structures can be manufactured using thermal spray technology. Tensile strength, elongation to break, and energy to break decrease with the filler content. Interpretation of the data and fracture surfaces provides an understanding of the fracture mechanisms.

Acknowledgments

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