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(54) A HIGH SHEAR-STRENGTH FIBER-REINFORCED COMPOSITE BODY

(71) We, GENERAL TECHNOLOGIES CORPORATION, a Corporation organised under the laws of the State of Delaware, United States of America, of 1821 Michael Faraday Drive, Reston, Virginia, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a high shear-strength fiber-reinforced composite body of the kind (hereinafter called "the kind defined") comprising a matrix, primary reinforcement fibers disposed substantially parallel to and spaced from one another, and secondary reinforcement fibers disposed between said primary fibers and oriented in a random or in a substantially regular manner, said fibers being distributed throughout and bonded within the matrix so that the body is of enhanced strength properties as compared with the material of the matrix alone.

The invention is intended to provide an improved composite body of the kind defined.

According to the invention there is provided a composite body of the kind defined, characterised in that the secondary fibers are in the form of single-crystal whiskers and the primary fibers are of diameters three or more times greater than the diameters of the said whiskers.

The production of single-crystal whiskers and whisker products or mat articles is described, for example, in U.S.A. Patent Specification No. 3 421 851 and U.K. Patent Specification No. 1 203 342 (Application No. 7003/68).

The invention is defined in the Claims hereinafter, and how it may be performed appears from the following description.

As the present invention involves the use of primary and secondary reinforcement fibers of significantly different diameters to provide a composite body having enhanced strength properties, and the smaller diameter fibers or whiskers are positioned between the larger diameter fibers, the whiskers can act to bind the larger diameter fibers to each other to increase the shear strength of the composite body. The larger diameter fibers are substantially parallel to one another i.e. aligned within the body and spaced so that the smaller diameter fibers can be distributed and oriented in random or more regular manner. An example of a high shear-strength composite body according to the present invention includes a matrix of resin material having embedded therein aligned boron filaments of larger diameter supported by smaller diameter discontinuous whiskers of alpha-alumina oriented at random and distributed throughout the matrix.

In the accompanying drawings FIGURES 1 and 2 are schematic illustrations of cross-sections of two fiber-reinforced composite bodies in accordance with the present invention.

FIGURE 1 shows a schematic illustration of a cross-section of a high shear-strength fiber-reinforced composite body of the kind defined comprising a matrix 10 which may be made of any suitable material for a particular structure and application. Plastics, resins, metals, ceramics and refractories are conventional matrix materials;

the plastics and resins include epoxy resins, polyesters and polyamides; the metals include aluminum, magnesium, silver, copper, nickel, iron, titanium, cobalt and their alloys. A ceramic matrix may include material selected from the materials listed below as possible constituents of fibers.

Within the matrix 10 are primary fibers 20 which form a first reinforcement in the composite body. The fibers 20 may be made of any reinforcement materials known to enhance the strength of a body including matrix material. The constituents of the fiber materials may include elements or compounds or alloys; for example oxides, nitrides, borides, carbides, and silicides, and glasses, may be used. Typical fiber materials include boron, graphite, silicon, beryllium, silicon carbide, silicon nitride, aluminum oxide, aluminum nitride, aluminum carbide, aluminum diboride, boron carbide, boron nitride, boron silicide, tungsten carbide, titanium diboride, titanium nitride, beryllium oxide, and beryllium boride.

The primary fibers 20 may be amorphous, polycrystalline, or single-crystal materials, and they may be present in the form of elongated or continuous filaments, or of short-length discontinuous fibers.

Direct adhesion between the matrix 10 and fibers 20 may be insufficient for good bonding, and then it is necessary to employ an intermediary or bridge material 30 between the matrix and reinforcement fibers. The intermediary material may be applied by coating either particles of the matrix material or the fibers with the coating agent 30. The coatings may not only increase the adhesion between the matrix and reinforcement fibers, but they may also improve the abrasion resistance and modulus of the composite body and its qualities at high temperatures. The coatings may be formed from inorganic materials, organo-metallic materials, or metals; often thin metallic coatings are used.

Between the primary fibers 20 of the composite body shown in FIGURE 1 are secondary smaller diameter reinforcement fibers 40. These fibers 40 may consist of material of the same composition as the larger diameter fibers 20, or be different in composition. The secondary fibers 40 are in the form of discontinuous single-crystal whiskers oriented at random and distributed between the larger diameter fibers 2. The whiskers 40 serve to bind the larger diameter fibers together so as to increase the overall high-strength properties of the body, particularly with respect to shear-strength characteristics. Preferably the whiskers 40 constitute at least 0.1 volume per cent of the composite.

The diameters of the primary fibers 20 are three or more times greater than those of the whiskers 40, and preferably ten or more times greater, even as high as 100 times greater. For example, a fiber 20 may have a diameter of from about 10-100 microns, and a whisker 40 may have a diameter of from about 1-3 microns. These values may vary widely depending upon the nature of the particular material used, and the intended application of the body. Similarly the lengths of the fibers 20 and of the whiskers 40 may vary widely, from elongated filaments to discontinuous fibers. The fibers 20 may be elongated filaments of boron, and the whiskers 40 may be discontinuous alumina whiskers.

The composite body may be made by any known technique for making fiber-reinforced composite bodies. A suitable method includes filament winding, and in this method a preformed mandrel in the shape of the desired structure is provided and the elongated fibers 20 are wound upon the mandrel. Then a mixture of matrix material having the whiskers 40 incorporated therein is applied over the fibers 20, which may be coated with a coating agent 30 before being wound on the mandrel. In this manner the fibers 20 are substantially parallel to and spaced from each other and aligned directionally in the resultant composite body, while the whiskers 40 are oriented at random and distributed between the larger diameter fibers 20.

The whiskers 40 improve the shear-strength of the composite body.

FIGURE 2 shows how the whiskers 40 may be of a geometrical structure such that the interlaminar shear-strength of the composite is improved.

The present invention may be utilized to provide composite bodies for many specific applications. One such application is that of a moulding composite body which includes discontinuous fibres of larger diameter (e.g. between 3 and 10 microns) and smaller diameter (e.g. between 0.2 and 1 micron) whiskers.

In suitable moulding procedures these moulding composite bodies have excellent flow properties with close packing and a high proportion by volume of the fibers. The bodies can be moulded readily to form articles having very small cross-sections, in the order of 2 mils or less in thickness. In addition to the high-strength properties of the moulding composite body (in the order of 10-15 million modulus) it exhibits excellent dimensional stability, and it may be moulded around and retain micrometallic inserts in electronic applications.

The following Examples indicate how the invention may be performed.

EXAMPLE 1

Elongated boron filaments each having a

diameter of about 100 microns, are wound on a mandrel to a desired shape. Then a fluent mixture of an epoxy resin containing discontinuous loose alpha-alumina whiskers having diameters of about 3 microns and lengths of about 400 microns is applied to the boron filaments to form a composite body containing 50 volume per cent of boron filaments and about 1 volume per cent of alpha-alumina whiskers. The shear strength of the composite when measured in a short-beam shear tester with three-point loading is found to be 14,000 p.s.i. whereas an otherwise similarly prepared composite body without alpha-alumina whiskers has a shear strength of only 8,000 p.s.i.

EXAMPLE II

A procedure otherwise substantially as in Example I is followed, using fiber-glass filaments of diameters of 10 microns in place of the boron filaments. An increase of 20% in the shear-strength is observed in such composite bodies as compared with composite bodies without alpha-alumina whiskers but otherwise of similar composition.

EXAMPLE III

A whisker product as referred to above in connection with Fig. 2 is incorporated into a composite body in substantially the same manner as described in Example I. At a whisker content of 1 per cent by volume an increase in the shear strength of the resultant composite body of about two times is observed.

EXAMPLE IV

A moulding composite body is prepared by mixing chopped short-length fiberglass filaments having diameters of about 10 microns and lengths of about 1/32 to 1/8 inches, a phenolic resin, and 1 1/2 per cent by volume of 1 micron diameter alpha-alumina whiskers having a length of about 400 microns. The composite body is moulded to a thickness of about 1 mil and has a tensile strength of 17,000 p.s.i. An otherwise similarly prepared composite body without the addition of the whiskers has a tensile strength of only 15,000 p.s.i. Further additions of fiberglass to the composite bodies result in no measurable increases in the tensile strengths, whereas further additions of the whiskers enhance the tensile strengths of the whisker-containing composite bodies.

WHAT WE CLAIM IS:—

1. A composite body of the kind defined, wherein the secondary fibers are in the form of single-crystal whiskers and the primary fibers are of diameters three or more times greater than the diameters of the said whiskers.

2. A body according to Claim 1, wherein said primary fibers are in the form of continuous filaments.

3. A body according to Claim 1 or 2, wherein said whiskers are present in an amount of at least 0.1 per cent by volume of said composite body.

4. A body according to Claim 1, wherein said primary fibers are discontinuous fibers.

5. A body according to any of Claims 1 to 4, wherein said primary fibers are in the form of fiberglass and said matrix is made of a resin.

6. A body according to any of Claims 1 to 4, wherein said primary fibers comprise boron.

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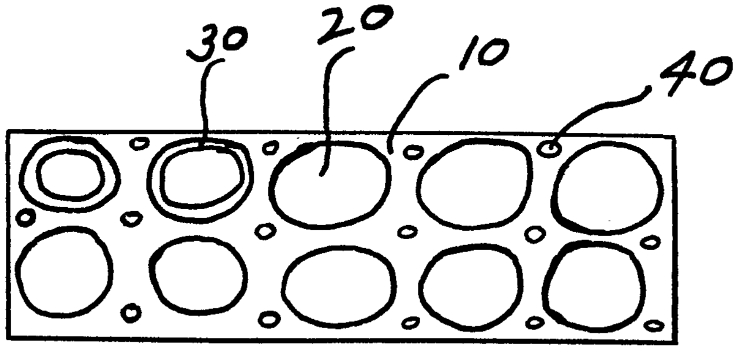

Fig. 1.

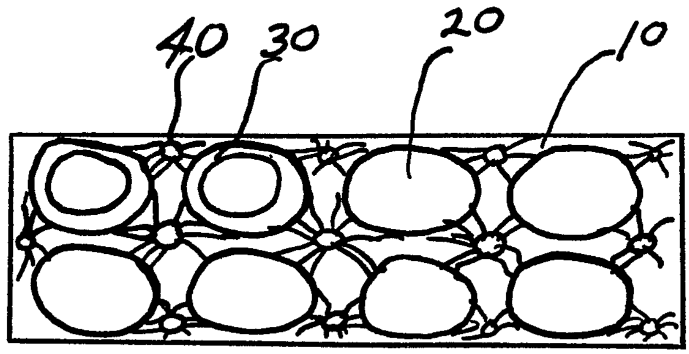

Fig. 2.