

TITLE OF THE INVENTION

Hybrid Composite Structure For Stiffness And Damping And The Method of Fabrication The Same

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

The present invention relates to a hybrid material, and in particular relates to a hybrid material structure having a high stiffness and increased damping. The present invention is also related to a method of fabrication of hybrid composite structure.

2. Description of the Related Art

- 10 US Patent Publication No. 20150258612 discloses a boring bar assembly comprising: a bar having a body and a cavity extending longitudinally along the body; a toolholder head adapted to receive a cutting tool attached to a distal end of the bar; a mounting structure attached to a proximal end of the bar, configured to attach the bar to a portion of the metalworking machine; and a tunable or tuned absorber inserted within the central cavity of
- 15 the body of the bar, wherein the body of the bar comprises a core layer formed from a first material and a coating layer formed from a second material and bonded to the first layer, wherein the second material having a higher modulus of elasticity than the first material. A tunable or tuned boring bar having increased stiffness is provided. Increasing the stiffness of the bar increases the natural frequency, thereby reducing directional deformation of the bar
- 20 during use. The tunable boring bar includes a distal portion configured to support a tool, a proximal portion configured for attachment to a support structure of a metal working machine, and a body, which is at least partially tubular, extending between the proximal portion and the distal portion. The tubular portion of the body has an elongated cylindrical cavity. The body of the boring bar includes a core layer formed from a first material and a coating layer formed
- 25 from a second material. The second material has a higher modulus of elasticity than the first material. In certain configurations, the coating layer bonded to the core layer by cladding, welding, chemical adhesives, chemical vapor deposition, pulsated plasma diffusion, or combinations thereof.
- 30 US Patent Publication No. 20130272811 relates to a composite tool body, and the composite tool body formed from a composition comprises i. a curable polymer and, ii. nanodiamond. The disclosure also relates to a high performance composite tool bar, and the tool bar comprises:

a composite body having a first end and a second end, the first end being capable of having a cutting tool mounted thereon; the second end being capable of being mounted to a driving device wherein the composite body is constructed from a curable polymer containing nanodiamond. Composite compositions and machine and contact tools, for example, metal boring tools and face mills that are manufactured from them. The tools are provided with composite structure to lighten the tools and yet retain the strength and durability of the tool. The novelty resides in the use of additives to certain composites that make up a portion of the tool, especially tool bars.

The use of mechanical structures is inevitable in any mechanical system. Stiffness is usually desired in a load bearing supporting structure. When the mechanical system is subjected to a varying load, dynamic stiffness is desired, the natural frequencies of the structure would be critical to the stability of the structure. Higher natural frequencies directly increases the bandwidth of the system, enabling a system to respond stably when subjected to higher frequency inputs, hence enabling the system to perform more aggressively yet achieving good dynamic response and positional accuracy.

Mass, stiffness and damping are the three parameters directly affecting the natural frequencies of the materials. Conventional methods of increasing the stiffness of a structure can be done by introducing additional geometric features to a structure of homogenous material. However this increases the overall mass, limiting the amount of stiffening features to be incorporated into a structure.

A vibrating body exhibits an oscillating behaviour when subjected to a disturbance from their stable equilibrium. Damping is the decay of the amplitude of each oscillation and a critically damped system can settle at a steady state without oscillating. Good damping is desirable for a stable system. Damping of a system can be contributed from the deformation of material or relative motion between interfaces occurring during vibration.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a hybrid composite structure which is made from two or more different material types of different geometrical shapes to build a structure with good stiffness and damping properties.

It is yet another object of the present invention to provide a hybrid composite structure for stiffness and damping, wherein the structure comprises a primary structure, and a secondary structure, acting as stiffeners attached to the structure, to complement the stiffness of the structure.

A further object of the present invention is to provide a hybrid composite structure for stiffness and damping, wherein a pre-stressed composite secondary structure applies a force at the interfaces with the primary structure and relative movement between the two structures allows energy dissipation through friction.

- 5 Yet still another object of the present invention is to provide a hybrid composite structure for stiffness and damping, wherein the shape of the primary structure is selected based on the interfaces thereof with the other structure and components mounted and the direction of the designed loads. Typically a rectangular cross section is selected due to its larger second moment of area resulting in higher bending stiffness. The secondary structure is designed
10 based on the geometry of the primary structure to complement stiffness in bending or torsion.

The present invention uses a hybrid of materials and geometric shapes to achieve a structure of higher stiffness and increased damping. The use of a hybrid of materials allows a structure to benefit from the properties of each material. Friction at the interfaces also provides energy dissipation which passively dampens the structure. Depending on the application, high
15 damping material can be sandwiched within the composite material to enhance effects of damping.

Another object of the present invention is to provide a hybrid aluminium and composite structure for stiffness and damping, wherein the primary structure of a square hollow section of aluminium material with an external dimension of 196.85 mm, a length of 1800 mm and a
20 thickness of 9.53 mm, with a secondary composite structure made of four carbon fiber quadrants of external radius 88.91 mm, thickness 2.5 mm and length 1800 mm.

The use of a material with good machinability as a primary structure is required to achieve a good geometrical tolerances at surfaces interfacing with another structure or component and incorporating geometric features into the primary member to enhance stiffness in bending or
25 reduce mass. The shape of the primary member can be selected based on either the nature of the load interfaces with other structures or mounting of other components onto it. An additional structure manufactured from a composite material would be designed to complements its stiffness in torsion be pre stressed and fitted into the primary structure to provide friction between the composite and primary structure.

30 An object of the present invention is to provide a method of fabricating a hybrid composition structure, the method comprising the steps of:

- (a) preparing a profile as a primary member having a hollow space within the primary member;

(b) associating a secondary member to form a circular hollow profile to be inserted within the hollow space of the primary member; and

(c) securing the secondary member to the inner surface of the primary member to fabricate the hybrid composite structure, wherein the secondary member can be pre stressed and fitted tightly within the primary member such that the fitting between the primary member and the secondary member allows energy dissipation through relative motion between the members.

Yet a further main object of the present invention is to provide a hybrid composite structure for stiffness and damping comprising

(a) a primary member having a hollow cavity as an interface designed to surround a secondary interface within the hollow cavity;

(b) a set of secondary members comprising of four quadrants and a crossed member, being made from high modulus material as the second interface, with thickness optimised, to provide stiffness for the primary member in torsion and bending, both sets of members being pre stressed and positioned within the hollow cavity of the primary member; and

(c) a set of holding members to secure the secondary member to the primary member such that the secondary members is pre stressed to apply a load at the interfaces, the relative motion between the primary member and the secondary member due to energy from an external force being dissipated through the deformation of the materials and friction at the interfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features, and advantages of the present invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a perspective view of an exemplary hybrid structure, assembled with a pair of guide rails and flexures, indicating its application as a bridge in a Cartesian robot in accordance;

FIG. 2 is an exploded view of the hybrid composite profile in accordance with the present invention;

FIG. 3 is a broken view of the hybrid composite profile, showing the carbon fiber quadrant within the hybrid composite structure in accordance with the present invention;

FIG. 4 shows one of the end views of the profile of the hybrid composite structure in accordance with the present invention; and

FIG. 5 is a close up view of the quadrants installed into the hybrid composite structure in accordance with the present invention.

- 5 The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a hybrid material structure having good stiffness and damping. Good stiffness and damping of a structure can be realised through the use of a combination
 10 of structural shapes and material. The combination of good stiffness, lower mass and good damping properties would result in a structure with higher natural frequency and stability under dynamic loading.

In a preferred embodiment of the present invention, a metallic, such as an aluminium square hollow profile as a primary member or primary structure together with a secondary member or
 15 structure such as a carbon fiber composite profile stiffener to significantly enhance the overall stiffness of the profile while minimising the increase in mass thereof. In this preferred embodiment, the method of attaching the secondary structure to the primary structure provides passive damping through the dissipation of energy through friction, due to relative motion between the interfaces of the two structures. The selection of designed shape of the primary
 20 structure is flexible to take the form of other shapes to accommodate its surrounding structures and components being mounted thereto, and directions of the designed load.

The present invention employs two or more different material types of different geometrical shapes to build a structure with good stiffness and damping properties. The hybrid structure comprises a primary structure and a secondary structure, acting as stiffeners attached to the
 25 hybrid structure, to complement the stiffness of the hybrid structure. Micro-slips at the interfaces between the primary structure and the secondary structure provides energy dissipation to improve the damping of the hybrid structure. A typical structure has a uniform square or rectangular hollow cross-section which has relatively better stiffness due to its shape, due to a larger second moment of area. However, it is relatively weaker in torsion as
 30 compared to an annular shape. Comparing a beam with an hollow circular cross-section of median diameter "D" and a hollow square beam with an median width "b" where the circumference of circle is equal to $4 \times b$, and both beams have the similar uniform thickness, length, applied load and its made of similar material. In bending, the hollow square beam is 1.7

times stiffer than the hollow circular beam. In torsion, the hollow circular beam would 1.6 times stiffer, with a shear stress 0.785 times lower (Gere and Timoshenko, Mechanics of Materials, Third SI Edition, 1991, Page 199, Example 2). To complement strength in torsion, a circular plate is introduced into its cross section.

5 Comparison of second moment of area between a Hollow Circular Tube to a Hollow Square Tube

$$I_{Hollow\ Square} = \frac{1}{12} [(b_2 - h_2^3) - (b_1 - h_1^3)] \quad I_{Hollow\ Circle} = \frac{\pi}{4} (r_2^4 - r_1^4)$$

$$\frac{I_{square}}{I_{circle}} = \frac{16}{3\pi} = 1.698$$

$I_{Hollow\ Square}$	– Second moment of a hollow square cross section
b_2	– Breadth of outside dimension of square cross section
b_1	– Breadth of inside dimension of square cross section
h_2	– Height of outside dimension of square cross section
h_1	– Height of inside dimension of square cross section
$I_{Hollow\ Circle}$	– Second moment of a hollow circle cross section
r_2	– Outside radius of hollow circle cross section
r_1	– Inside radius of hollow circle cross section

10 Comparison of Shear Stress between a Hollow Circular Tube to a Hollow Square Tube

$$\frac{T_1}{T_2} = \frac{A_{m2}}{A_{m1}} = \frac{b^2}{\pi r^2} = \frac{\pi}{4} = 0.785$$

T_1	– Shear Stress of hollow circular tube
T_2	– Shear Stress of hollow square tube
A_{m2}	– Cross Section of hollow square tube
A_{m1}	– Cross Section of hollow circular tube
b	– Mean of outside and inside breadth or height of square tube
r	– Mean of outside and inside radius of circular tube

Comparison of Angle of Twist between a Hollow Circular Tube to a Hollow Square Tube

$$\frac{\varphi_1}{\varphi_2} = \frac{J_2}{J_1} = \frac{\pi^2}{16} = 0.617$$

φ_1	– Angle to twist of circular tube
φ_2	– Angle to twist of hollow square tube
J_2	– Polar moment of inertial of hollow square tube
J_1	– Polar moment of inertial of circular tube

To minimise the increase in mass, carbon fiber composite is used for the circular plate. The circular plate is designated in four quadrants to be able to easily installed and fitted tightly into the profile of the primary structure. A holding stripe is installed along the length of the primary structure, which pushes outward against the edge of the quadrants (that make up the secondary structure) and holds the edges of the wedges of the strips against the primary structure. The wedge of the holding stripe allows the plates to be directly in contact with the structure for the external loads to be transmitted to the quadrants plates. The interference fitting also allows energy dissipation wherein there is relative motion between the primary structure and the quadrant plates, increasing the damping performance of the primary structure.

FIG. 1 illustrate an exemplary a schematic view of the hybrid composite structure 100, assembled with a pair of guide rails 13 and a plurality of flexures , indicating its application as a bridge in a Cartesian robot in accordance with a preferred embodiment of the present invention.

In the present preferred embodiment, the primary structure or member 10 is an aluminium square hollow elongated structure having a cross section of 196.85 mm, and a length of 1800 mm, with a thickness of 9.53 mm. Other type of metal structure can be used such as carbon steel, stainless steel, a reinforced steel composite, magnesium could be used. Four carbon fiber quadrants 12 (which make up the secondary structure or member) of thickness 2.5 mm are employed and fitted inside the hollow section of the primary structure (member) 10. There are 4 holding strips 42 to hold the carbon fiber quadrants 12 to the inside of the primary structure 10. The stripes 42 are held by a plurality of screws or any other kinds of fasteners. After the carbon fiber quadrants 12 are placed into the primary structure 10, the holding strips 42 are then tighten to push the carbon fiber quadrants 12 slightly apart. This will allow the carbon fiber quadrants 12 to bend and be pre stressed, allowing the quadrants 12 to have direct contact with the primary structure or member 10.

In accordance with the present invention, the primary structure or member 10 is designed to mount a linear motor (not shown) where the end effector would be mounted to. On one or both of the two ends carried by a carriage 14 and the primary structure 10 is simply supported at both the ends 14 by flexures, where one is a two point and the other is a three point mount.

Therefore, under static load, when the load is positioned at the center of the primary structure or member 10, the primary structure 10 will experience a bending and torsional load. In that configuration, when the primary structure 10 is subjected to an external rhythmic load, the primary structure 10 would eventually oscillate in a bending and or twisting motion. The frequency which the primary structure 10 oscillates is increased as compared to a plain structure or similar structure of a homogenous material. The present invention provides a significant increase in stiffness while minimising the increasing in mass of the material used. The damping coefficient of the primary structure 10 is also increased due to the dissipation of energy through friction between the carbon fiber plates 12 of the secondary member 22 and the primary structure 10 inner surface. The increase in stiffness and damping coefficient effectively allows the hybrid composite structure of the present invention to be dynamically stable under higher input frequencies. The flexing of the carbon fiber quadrants 12 during deformation of the primary structure 10 also aids in the dissipation of energy.

As shown in FIG. 2, an exploded view of the hybrid composite structure 100 depicting how the structure is fabricated. The carbon fiber quadrants 12 of the secondary member or structure 22 are held to the primary member or structure 10 by 4 holding strips, and the assembled quadrants 12 form a circle within the primary member 10. The end covers 14 of the primary member 10 would constrain both ends of the carbon fiber plates 12 and further stiffen the primary member 10 in torsion. In the prefer embodiment of the present invention, two guide rails 13 can be used to mount a carriage (not shown) moving across the primary structure 10. Both the ends 14 of the primary member 10 can be mounted onto a flexture mount positioned at the bottom of the primary structure 10 where each end of the primary structure can be driven by a separate axis.

FIG. 3 is a schematic broken view of the hybrid composite structure, showing the carbon fiber quadrants of the secondary member 22 within the primary structure 10 in accordance with the present invention. The four quadrants 12 of the secondary member 22 is pushed against the four inner walls of the hollow primary structure 10.

FIG. 4 shows the end view of the hybrid composite structure in accordance with the present invention. As shown in the figure, four holding strips 42 are fastened to the inner wall 43 of the primary structure or member 10. The holding strip 42 has a wedge shape and is used to push the carbon fiber quadrants 12 against the inner wall 43 of the primary structure or member 10.

FIG.5 shows an enlarged view of the quadrants 12 fitted onto the inner wall 43 of the primary member or structure 10. The pre stressed quadrants presses its ends against the wedge holder and inner wall of the primary member, creating an interference fit between the ends of

the carbon fiber quadrants 12 and the primary member or structure 10, which creates a damping effect when there is relative motion between the two surfaces.

The primary structure 10 is machined to create with stiffener feature at the center, across each face of the primary structure 10 to reduce its mass. The front of the primary structure 10 is machined with mounting features for a linear motor to be mounted. The shape of the primary structure has good bending stiffness but relatively weaker in torsional stiffness. Along the centre stiffener feature of each side, a plurality of holes are drilled to mount the holding strips in place. Mounting holes are drilled at both ends and all mounting surfaces are machined to ensure that their flatness are within tolerance. Four carbon fiber plates of 1800 mm long are moulded in the shaped of a quadrant by vacuum bagging techniques. The carbon fibers are laid with the outermost layers in the longitudinal direction and three intermediate layers in the radial direction, separated by two layers at 45 degrees. The edges along the length of the carbon fiber plates are cut at angle of 105 degrees from the tangent of the quadrant 12. The moulded quadrants are cut to size by water jet cutting.

The wedge shape holding strips 42 with a cross section in the shape of a T, with a 15 degree at both sides to push against the edge of the carbon fiber quadrants. The tightening of the strips would allow the wedge to be pushed against the edge of the carbon fiber and the T feature prevents the edge of the strip from the dislodging from the edge. The preloading of quadrant creates an interference fit between the carbon fiber and the profile, allowing load from the profile to be directly transferred to the carbon fiber quadrants. Flexing of carbon fiber quadrants 12 and compressive forces with each quadrant 12 and the primary member 10 creates friction between the interfaces which dissipates energy when there is a relative motion between the primary member and the carbon fiber quadrants, 12, creating a passive damping effect.

In the preferred embodiment of the present invention, the secondary member 22 is made from a material which is of lightweight and of high modulus and can be manufactured as a single or sandwich material, and the secondary member is enclosed or encompassed by the primary member.

The primary member is an external structure allowing the insertion of the secondary member therein. The material for the primary member is aluminium, carbon steel, stainless steel, a reinforced steel composite, or any combination thereof, and the material for the secondary member is selected from the group consisting of carbide, carbon fiber, a carbon composite material, or any combination thereof. In the fabrication process, the securing of the secondary member to the primary member is bonded at the outer portion of the secondary member by the holding member.

In accordance with the present invention, there is provided a method of fabricating a hybrid composition structure. The method comprises the steps of :

- (a) preparing an extruded metallic profile structure as a primary member having a hollow space therewithin;
- 5 (b) associating a secondary member to form a circular hollow profile structure to be inserted within the hollow space of the primary member 10, wherein the circular hollow profile structure is made of carbon fiber material in the form of 4 quadrants; and
- (c) securing the secondary member 22 to the inner surface of the primary member 10 to fabricate the hybrid composite structure 100, wherein the secondary member 22 can fit tightly
10 within the primary member 10 such that the fitting between the primary member 10 and the secondary member 22 allows energy dissipation when there is a relative motion between the members 10, 22.

While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed
15 embodiments. It is to be understood that the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

CLAIMS

1. A hybrid composite structure for stiffness and damping comprising
 - (a) a primary member as an interface, optimised for bending stiffness, being a hollow cylindrical or square structure allowing the insertion of the secondary member therein, having a hollow cavity and a cross section designed to surround a second interface within the hollow cavity; wherein the material for the primary member is aluminium, carbon steel, stainless steel, a reinforced steel composite, or any combination thereof;
 - (b) a secondary member as the second interface, optimised to provide stiffness for the primary member in primary torsion and in bending, being made from high modulus carbon fiber material and being positioned within the hollow cavity of the primary member, wherein the secondary member is formed from 4 carbon fiber plates or quadrants, wherein the primary member allows the insertion of the secondary member therein; and
 - (c) a holding member to secure the secondary member to the primary member in such a way that a relative motion between the primary member and the secondary member is available to dissipate energy formed from an external oscillating load.
2. The hybrid composite structure for stiffness and damping as set forth in Claim 1, wherein the material for the primary member provides good machinability to achieve geometrical accuracy and precision in the mounting surfaces thereof.
3. The hybrid composite structure for stiffness and damping as set forth in Claim 1, wherein the energy is being dissipated via friction between the interfaces such as between the primary member and the secondary member, or the secondary member in the course of torsional or bending vibrations, where torsional deformation and sliding of the quadrant or plates allows for energy dissipation.
4. The hybrid composite structure for stiffness and damping as set forth in Claim 1, wherein the secondary member is made from a material which is of lightweight and of high modulus and is able to be manufactured as a single or sandwich material.
5. The hybrid composite structure for stiffness and damping as set forth in Claim 1, wherein the secondary member is enclosed or encompassed by the primary member.
6. The hybrid composite structure for stiffness and damping as set forth in Claim 1, wherein the material for the secondary member is selected from the group consisting

of carbon fiber composite, glass fiber composite, aramid composite, flax composite or any combination of material thereof.

- 5 7. The hybrid composite structure for stiffness and damping as set forth in Claim 1, wherein the securing of the secondary member to the primary member is bonded at the outer portion of the secondary member by the holding member.