The invention provides rear suspension structures and engine cradles involving tubular components. The tubular components have variable wall thickness along the length for reducing materials required. The tubular components also have mechanical properties varying along the length of the tubular components, to meet the requirements on strength and dynamic and static loads. The weight of the tubular components can be further reduced by appropriately varying the wall thickness and mechanical properties along the length of the tubular components.
VEHICLE STRUCTURAL COMPONENTS MADE FROM TUBULAR MEMBERS AND METHOD THEREFOR

[0001] This application claims the benefit of U.S. Provisional Application No. 60/614,494 filed on Oct. 1, 2004.

1. FIELD OF INVENTION

[0002] The present invention relates to structural components used in vehicles and a method of forming same.

2. BACKGROUND OF INVENTION

[0003] In the automotive industry, various structural components are of late made from tubular blanks. This is mainly due to the fact that tubular components can often combine strength with significant weight and material reduction.

[0004] In manufacturing the above mentioned structural components, it is known to design the tubular blanks with a variable wall thickness in order to, inter alia, have localized reinforcement in regions of the components that are subject to stress. Various methods have been suggested to provide such blanks with variable wall thickness. For example, the method taught in U.S. Pat. No. 5,333,775 provides a blank comprised of tubular pieces of different wall thickness that are welded together to form the blank. Although resulting in the required variable wall blank, this method is not entirely satisfactory for several reasons. Firstly, the method involves the pre-forming step of creating the blank using a welding procedure, which adds a considerable amount to the total processing time. Secondly, the presence of welds may lead to weak spots in the formed product. Thirdly, the sudden changes in wall thickness associated with this method also tend to introduce undesirable physical properties of the final product. The management of impact energy and design of dynamic properties also tend to become more difficult as a result.

3. SUMMARY OF INVENTION

[0005] The invention provides vehicle structural components, such as rear suspension structures and engine cradles, made from tubular blanks. In one aspect, the tubular blanks are provided with a variable wall thickness along their lengths. In another aspect of the invention, the tubular blanks also have variable mechanical properties along their lengths.

[0006] In a first aspect of the invention, there is provided a cross member for a rear suspension assembly. The cross member comprises a unitary tubular member, the tubular member having a variable wall thickness along its length. The tubular member has a generally elongated center portion, a pair of end portions and a pair of intermediate sections each formed between the center portion and one of the end portions. The pair of intermediate sections integrally connecting the end portions to the center portion. The center portion defines a longitudinal axis along the center portion and each of the end portions is displaced from and generally parallel with the longitudinal axis. The wall thickness at the end portions is smaller than the wall thickness at the intermediate sections.

[0007] In another aspect, there is provided an engine support structure for supporting an engine of a vehicle. The engine support structure includes a pair of side rails spaced from each other, and a front cross member and a rear cross member spaced from the front member, the front and rear cross members joining the side rails to form a general quadrilateral shape. Each of the side rails is formed from a unitary tubular member. The unitary tubular member has a variable wall thickness along its length, the wall thickness monotonically increasing along the unitary tubular member in a forward direction in a substantial portion of the unitary tubular member.

[0008] In yet another aspect of the invention, there is provided a vehicle seat support structure for mounting a seat to a vehicle. The seat support structure includes an elongated side impact cross member formed from a blank tube and a seat frame mounted on the impact cross member for mounting the seat thereon. The side impact cross member has an integral end portion, the end portion being adapted to connect the side impact cross member to the vehicle. The side impact cross member is tubular and has a variable wall thickness along its length; wherein the wall thickness is smallest at the end portion.

[0009] In another aspect, there is provided a method of making a unitary tubular component from a metallic blank tube. The tubular component has a variable wall thickness and a desired shape. The method includes the steps of placing the blank tube in a die and mandrel assembly, passing the blank tube through the die and mandrel assembly to form a tubular blank, the tubular blank having a wall thickness varying along its length, and placing the tubular blank in a forming die and forming the tubular blank into the desired shape.

[0010] In other aspects the invention provides various combinations and subsets of the aspects described above.

4. BRIEF DESCRIPTION OF DRAWINGS

[0011] For the purposes of description, but not of limitation, the foregoing and other aspects of the invention are explained in greater detail with reference to the accompanying drawings, in which:

[0012] FIG. 1 is a top perspective view showing a rear suspension assembly having a tubular cross beam according to an embodiment of the present invention;

[0013] FIG. 2A is a front elevation view showing the tubular cross beam of the rear suspension assembly shown in FIG. 1;

[0014] FIG. 2B is a typical stress distribution map, showing the stress distribution in a cross beam of FIG. 1;

[0015] FIG. 2C is a top perspective view showing another exemplary cross beam having a different wall thickness variation along the tube;

[0016] FIG. 3 is a longitudinal cross sectional view of a tubular blank that can be further formed for making a tubular cross beam shown in FIG. 2A;

[0017] FIG. 4A is a longitudinal cross sectional view of another tubular blank according to an embodiment of the present invention;

[0018] FIG. 4B is a longitudinal cross sectional view of yet another tubular blank according to an embodiment of the present invention;
[0019] FIG. 5 is a cross sectional view of a die and mandrel apparatus for forming a tubular cross beam of FIG. 2A;

[0020] FIG. 6 is a perspective view of a hydroforming die for forming a tubular cross beam shown in FIG. 2A;

[0021] FIG. 7 is an end view of the die of FIG. 6 in an open position;

[0022] FIG. 8 is an end view of the die of FIG. 6 in a closed position;

[0023] FIG. 9 is a perspective view of an engine cradle having tubular side rails according to an embodiment of the present invention;

[0024] FIG. 10 is a perspective view of a car seat support assembly attached to a side of a vehicle body frame; and

[0025] FIG. 11 is a side view of the car seat support assembly of FIG. 10.

5. DETAILED DESCRIPTION OF EMBODIMENTS

[0026] The description which follows and the embodiments described therein are provided by way of illustration of an example, or examples, of particular embodiments of the principles of the present invention. These examples are provided for the purposes of explanation, and not limitation, of those principles and of the invention. In the description which follows, like parts are marked throughout the specification and the drawings with the same respective reference numerals.

[0027] FIG. 1 shows a rear suspension assembly 100. As is well known, a rear suspension serves to connect a vehicle body to the rear road wheels. FIG. 1 shows a rear suspension for a vehicle whose rear wheels are not driven nor steerable. However, it will be understood that the invention is not limited to such rear suspensions.

[0028] As can be seen from FIG. 1, the rear suspension assembly 100 has a tubular cross member, or cross beam 102. Mounted to each end of tubular cross beam 102 is an end plate 104. End plate 104 has a spindle hole 106 for mounting a wheel assembly (only rotor 108 is shown). As will be understood, a road wheel can be mounted to rotor 108 through wheel studs provided thereon. Near each end of the tubular cross beam 102 and inboard thereof is attached a lower arm 110. At the distal end of the lower arm 110 is provided a connection bracket 112 for connecting the rear suspension assembly 100 to the body or frame of the vehicle. Also attached to the tubular cross beam 102 and near each end thereof is a spring seat 114. A coil spring 116 is positioned on the spring seat 114 to provide cushioning between rear suspension assembly 100 and the underside of the frame or floor of the vehicle.

[0029] The cross beam 102 is a unitary tubular component, produced from a one-piece tubular blank, as will be described later. As can be seen in FIG. 2A, the cross beam 102 has a generally straight center section 120, which defines a longitudinal cross beam axis 122. At each end of the cross beam 102 are generally straight end sections 124a, 124b. The end sections are shorter than the center section 120. The longitudinal axes of the end sections 124a, 124b generally lie in the same plane. As can also be seen, the plane containing the longitudinal axes of the end sections 124a, 124b is generally parallel to the plane containing the longitudinal axis of the center section 120 but displaced therefrom at a distance d. Intermediate sections 126a, 126b connect each end section 124a, 124b to the center section 120. The center section 120 and the intermediate sections 126a, 126b form a generally 'U' shaped structure. The aforementioned profile of the rear suspension provides the sufficient ground clearance between ground and the vehicle body, or any components attached to the center section 120. It will be appreciated that the center section 120 may not necessarily be straight, as long as it can provide the required clearance.

[0030] As will be known to person skilled in the art, a rear suspension cross beam is subjected to uneven load distribution, either static or dynamic, in normal use. To meet the maximum load requirements, a tubular cross beam of uniform wall thickness can be produced. Such a cross beam will require a wall thickness that is based on the maximum load. However, such a cross beam tends to require more material than necessary, which contributes to unnecessary weight of the component and waste of material. To meet the structural requirements, such stress and stress distributions under various conditions are often analyzed and studied. FIG. 2B is a typical stress distribution map from such studies. The map shows concentrated strain energy, or stress, in the vicinity of bends 128. On the other hand, towards both ends of the cross beam, the stress is shown to be lower.

[0031] According to the invention, the wall thickness of the cross beam 102 can be varied along its length to provide localized strengthening to meet these stress variations. Similarly, those regions of the cross beam not subjected to stress can be provided with reduced wall thicknesses. An example of such a variable wall thickness is illustrated in FIG. 2A. As illustrated in FIG. 2A, the end sections 124a, 124b of the tubular cross beam 102 are formed with a first wall thickness t1. Both intermediate sections 126a, 126b are formed with a second wall thickness t2. According to the invention, the thickness t2 is greater than the first wall thickness t1, since the intermediate section would typically be under greater stress. By way of example, the first wall thickness t1 is 3.3 mm and the second wall thickness t2 is 5.5 mm.

[0032] FIG. 2C shows another exemplary mass distribution, or wall thickness variation along the cross beam. Tubular cross beam 102' shown in FIG. 2C is similar to that shown in FIG. 2A, except that the wall thickness is the largest in the center region of tubular cross beam 102'.

[0033] As will be understood, for different vehicles and different components, there may be a different stress distribution map. In other words, the specific locations or regions of a tubular component that require increased or reduced wall thickness will vary from vehicle to vehicle and from component to component. The examples provided herein are for illustrative purpose only.

[0034] FIG. 3 illustrates a tubular blank that can be further formed for making a tubular cross beam 102. As illustrated, the blank 200 comprises a tubular member having a generally uniform outer surface 202 and a generally uniform outer diameter D1. The blank 200 is formed with a variable wall thickness, as described further below, such that at desired portions, the wall thickness is either reduced or increased thereby resulting in a larger or smaller inner diameter. FIG.
3 illustrates several constant wall thickness regions, including two end regions 204, a constant wall thickness center region 206. Also shown are two enhanced wall thickness regions 208, each being formed between the center region 206 and an end region 204. In the end regions 204, the wall thickness is \( t_e \). In the enhanced wall thickness regions 208, the wall thickness is increased to \( t_e \). In the center region 206, the wall thickness is \( t_e \). As will be appreciated, the wall thickness of the center region \( t_e \) can be larger or smaller than \( t_e \) depending upon the specific characteristics of the required blank. The wall thickness of each region is circumferentially uniform.

[0035] It will be understood by persons skilled in the art that various other longitudinal cross sectional profiles will depend upon the specific requirements of the blank. Further, although the blank 200 is illustrated as being symmetric when viewed axially from each end, it will be understood that this is not necessary as different constant wall thickness regions may be provided along the length of the tube according to the specific need.

[0036] FIGS. 4A and 4B provide further examples of tubular blanks having variable wall thickness. FIG. 4A illustrates a tubular blank 200' that has a tapered section 212 with a gradually changing wall thickness. FIG. 4B illustrates another tubular blank 200' that has a number of different wall thickness sections.

[0037] The tubes of the present invention having varying wall thicknesses can be produced as described below. In a preferred embodiment, the blank is formed by passing a tube of constant wall thickness through a die and mandrel assembly. An example of a die and mandrel assembly that can be used in the present invention is illustrated in FIG. 5. As shown, the die and mandrel assembly 214 comprises a die 216 having die cavity 218. A mandrel 220 is provided at one end of a rod 222. The rod 222 is attached, at its other end, to a control mechanism that allows the mandrel to be inserted and withdrawn from the die cavity 218 in a reciprocating manner as indicated by the short arrow 224. An original tube 230 is attached at a first end to a draw machine, not shown. The first end of the tube is then drawn through the die cavity so as to result in a drawn tube 232 having a constant outer diameter. The direction in which the tube is drawn is indicated by the long arrow 234. The die cavity 218 is provided with a first opening 236 having a diameter to allow the passage of the original tube 230 and a second opening 238 having a diameter to allow the passage of drawn tube 232. As can be seen, the diameter of second opening 238 is less than that of first opening 236. Accordingly, the diameter of the drawn tube 232 is generally less than that of the original tube 230.

[0038] As shown, the mandrel 220 is positioned within the interior of the original tube 230 and is generally co-axial therewith. A ring gap is formed between the mandrel and the die. If the mandrel is moved into the die cavity 218, the wall of the original tube 230 passing through the die cavity 218 is constricted. If the mandrel is removed from the die cavity, such constriction is not effected. Therefore, by reciprocating the mandrel 220 in and out of the die cavity 218 while the original tube 230 is drawn therethrough, the size of the ring gap can be varied so as to control the wall thickness of the tube at desired locations along its length. As illustrated in FIG. 4, the drawn tube 232 includes thin wall regions 240 and 242, separated by a region where the wall thickness is not affected, 246. As shown in FIG. 5, the mandrel 220 is provided with a small diameter portion 221 and a large diameter portion 223 joined by a tapered portion 225. The large diameter portion 223 is connected to the rod 222.

[0039] As will be appreciated, it is possible to form the blank to have a number of different wall thicknesses by varying the mandrel used or the location of the mandrel within the die. By coordinating the speed of the motion of the mandrel and the speed at which the tube is drawn, sections of gradual change of wall thickness can also be formed.

[0040] Once the drawn tube 232 described above is formed, the drawn tube 232 may be subjected to localized heat treatment to vary local mechanical properties, such as yield stress (YS), ultimate tensile strength (UTS) or hardness, among others, along its length. Local heat treatment may be performed in any suitable manner. In one embodiment, induction heating is employed for its controllability.

[0041] As will be appreciated, cold forming of a tubular component tends to harden the material. This hardening will occur when forming a tube blank of variable wall thickness as well as during the stages of bending and hydroforming, as will be described later. Generally, material hardening increases more notably in areas of bends or in regions where the wall thickness has been significantly reduced. As also will be understood, the stiffness of the tubular component along its length tends to correlate with the local wall thickness. These variations, namely the variation of mass, stiffness and material hardening, along the tube tend to affect not only the static, but also the dynamic physical properties of the tubular component after it is finally formed. It is desirable to vary the static and dynamic physical properties of the tube to meet the requirements imposed by design objectives. While wall thickness may be varied to meet the load bearing requirements, a further selective heat treatment step can be applied where necessary to control or target certain mechanical properties in selected areas, such as bends or thin wall areas. Tubular components with this controlled and combined variation in mass and mechanical properties along the tube tend to more easily meet load and dynamic characteristic requirements with further reduced mass. Although frequent references are made to variations of mechanical properties along the tube, it will be understood that a tubular component having uniform mechanical properties along its length is but one special case.

[0042] In a heat treatment step, heating is applied to selected sections of the drawn tube 232 to adjust the local mechanical properties along its length. More specifically, the cold forming process used to vary the tube wall thickness generally results in a hardening of the material. This hardening may adversely affect the dynamic properties of an finished article. Some sections, such as those that will eventually (after final forming) comprise bends in the final article, may need to be rendered more malleable to withstand the bending process, which also tends to adjust the physical properties of the finished article at the same time. Such malleability may be provided by a local heat treatment. Generally, the amount of change in local mechanical properties after the tube blank is bent and hydroformed is known. By appropriately heat treating, or annealing these regions prior to the bending and hydroforming stages, a desirable
distribution of mechanical properties in the final product may be obtained. Heat treating the blank tube prior to bending or hydroforming also facilitates the bending and hydroforming steps as annealing the tube generally softens the tube at the annealed sections.

[0043] The drawn tube 232, or if heat treated, the heat treated tube, may be cut to the desired length, if needed. In another embodiment, the desired length may be cut prior to inserting into the die and mandrel assembly, whereby the drawn tube 232 comprises the tube blank itself. Alternatively, a cut tube blank may also be pressed through the die and mandrel assembly. In any one of these cases, the blank of varying wall thickness is then further processed, where necessary, and formed to the desired final shape as described further below.

[0044] After an appropriately cut drawn tube 232 is formed, and if needed, heat treated, it is bent in the desired two or three dimensional shape. A forming stage, such as a hydroforming stage, may further be used to impart a desired cross sectional shape or shapes. If the final tubular component is straight, no bending may be needed. In the forming stage, the tube blank is delivered to a forming station. In the preferred embodiment, such forming station comprises a hydroforming station as is commonly known in the art. An example of a typical hydroforming apparatus is illustrated in FIG. 6.

[0045] As shown in FIG. 6, a hydroforming apparatus generally includes a forming die 244 having two cooperating sections 246 and 248. Each of the two cooperating sections 246 and 248 are provided with one half of a forming die cavity 250. When the two cooperating sections 246, 248 are in a closed position, they form a forming die cavity 250. The forming die cavity 250 is formed with the desired overall and cross sectional shape of the final component being made.

[0046] As illustrated in FIG. 6, a pre-formed drawn tube blank 252 is placed within the forming die cavity when in the open position, as shown in FIGS. 6 and 7. As can be seen, the drawn tube blank 252 is initially formed in the desired general shape of the desired element, including the required bends etc. Once in the forming die cavity 250, the two sections 246 and 248 are closed, wherein both sections are in contact thereby forming and sealing the forming die cavity 250. The ends of the drawn tube blank 252 are then sealed and the interior of the drawn tube blank 252 is pressurized until the blank assumes the desired shape defined by the forming die cavity 250, including the cross sectional shape of the forming die cavity, as illustrated in FIG. 8. A completely formed tubular component 254 thus results.

[0047] It will be understood that the hydroforming apparatus illustrated in FIGS. 6 to 8 is simplified so as to illustrate the general principle. Various parts of the complete apparatus, such as seals, valves, control and pumping units etc., have been omitted for the purpose of clarity. However, such apparatus will be apparent to persons skilled in the art. It will also be understood by persons skilled in the art that although a hydroforming process has been described, various other forming processes may also be used in method of the present invention.

[0048] The method described above can be used to make other tubular structural members. FIG. 9 shows an engine support structure, or engine cradle 300. Engine cradle 300 provides a support structure for supporting an engine and securing it to a vehicle frame. The engine cradle 300 has a front cross member 302 and a rear cross member 304, extending between a pair of longitudinally extending side rails, left side rail 306 and right side rail 308. Front cross member 302 and rear cross member 304 are secured to side rails by secure brackets, namely front secure brackets 310 and rear secure brackets 312. Secure brackets may be welded to side rails and cross members, or secured to side rails in any other suitable manner such as by bolting. Engine cradle 300 is connected to vehicle body or frame through resilient connectors 314 to reduce vibration transmitted to the vehicle.

[0049] Side rails 306, 308 are shown to be spaced from each other and are generally parallel with each other as well. Similarly, front and rear cross members 302, 304 are also shown to be spaced from each other and are generally parallel with each other as well. Side rails and cross members, when joined together, form a general rectangular shape. However, it will be appreciated that these four components may be joined to form any other quadrilateral shape and is not restricted to a general rectangular shape as shown. Further, the quadrilateral shape is not necessarily restricted to a two dimensional shape as the side rails and front and rear cross members may not necessarily be straight. A general three dimensional shape having four sides may result.

[0050] Each end of the side rails extend beyond the general rectangular shape and diverges from the corresponding end of the opposite side rail, for providing better stability to the engine rested upon the engine cradle 300. As shown, resilient connectors 314 are provided in the end portions of side rail for connecting the engine cradle 300 to a vehicle frame or body.

[0051] In general, in a crash, front end of an engine cradle takes more load than its rear end. It is therefore advantageous to provide side rails that are stronger in the front than in the rear section. Side rails shown in FIG. 9 has a substantially portion, namely a portion approximately corresponding to a side of the general rectangular shape, enhanced with the wall thickness thereof increasing gradually and monotonically towards the front. A tube blank such as that shown in FIG. 4A may be conveniently used for producing such a side rail. Such a gradual and continuous increase in wall thickness toward the front end helps to achieve the desired strength without having to add unnecessary weight to the engine cradle 300.

[0052] FIG. 10 shows a car seat support assembly 400. The car seat support assembly 400 is shown as attached to the side of a car body frame 402. The car seat support assembly 400 has a side impact cross member 404 for supporting a car seat frame 406 therein. A pair of track bars 408 are provided between the side impact cross member 404 and the car seat frame 406 to allow a car seat to be moved along the track bars 408 back and forth.

[0053] As shown more clearly in FIG. 11, side impact cross member 404 defines a general beam center axis 410. The side impact cross member 404 has a center tunnel mount area 412. A bend area 414 is formed on each side of the center tunnel mount area 412 to displace it from but keeps it generally parallel with the general beam center axis 410.
[0054] During a side impact, it is important that the side impact cross member 404 does not buckle in the tunnel mount area 412, nor the track mount area 416. Any crush in the bend area 414 is also to be avoided. Preferably, the impact energy is directed toward either or both ends such that the impact energy is absorbed by the deformation of the end portions 418. FIG. 11 also shows the variation of wall thickness along the side impact cross member for achieving the energy management and stress requirements described above. As can be seen, the wall thickness is reduced in the end portions 418 of the side impact cross member 404. This promotes the deformation of the side impact cross member 404 in the end portions, but not other sections. Preferably, as can be seen in FIG. 11, wall thickness is also increased in the bend area 414 to discourage buckling and crush.

[0055] Various embodiments of the invention have now been described in detail. Those skilled in the art will appreciate that numerous modifications, adaptations and variations may be made to the embodiments without departing from the scope of the invention. Since changes in and or additions to the above-described best mode may be made without departing from the nature, spirit or scope of the invention, the invention is not to be limited to those details but only by the appended claims.

What is claimed is:

1. A cross member for a rear suspension assembly, the cross member comprising:

   a unitary tubular member, the tubular member having a variable wall thickness along its length;

   the tubular member having a generally elongated center portion, the center portion defining a longitudinal axis along the center portion;

   the tubular member including a pair of end portions and a pair of intermediate sections each formed between the center portion and one of the end portions, said pair of intermediate sections integrally connecting the end portions to the center portion;

   each of the end portions being displaced from and generally parallel with the longitudinal axis,

   wherein the wall thickness at the end portions is smaller than the wall thickness at the intermediate sections.

2. The cross member of claim 1, wherein the wall thickness is larger at the center portion than at the bend portions.

3. The cross member of claim 1, wherein the wall thickness is smaller at the center portion than at the bend portions.

4. An engine support structure for supporting an engine of a vehicle, the engine support structure comprising:

   a pair of side rails spaced from each other; and

   a front cross member and a rear cross member spaced from the front member, the front and rear cross members joining the side rails to form a general quadrilateral shape,

   wherein each of the side rails is formed from a unitary tubular member, the unitary tubular member having a variable wall thickness along its length, the wall thickness monotonically increasing along the unitary tubular member in a forward direction in a substantial portion of the unitary tubular member.

5. The engine support structure of claim 4, wherein the substantial portion extends between the rear cross member and the front cross member.

6. A method of making a unitary tubular component from a metallic blank tube, the tubular component having a variable wall thickness and a desired shape, the method comprising the steps of:

   placing the blank tube in a die and mandrel assembly,

   passing the blank tube through the die and mandrel assembly to form a tubular blank, the tubular blank having a wall thickness varying along its length, and

   placing the tubular blank in a forming die and forming the tubular blank into the desired shape.

7. The method of claim 6, further comprising the step of:

   heat treating the tubular blank at selected locations to adjust mechanical properties of material thereat.

8. The method of claim 7, wherein the tubular blank is heat treated at a location where a bend is formed.

9. The method of claim 7, wherein the tubular blank is heat treated at a location where the wall thickness is reduced.

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