A method of manufacturing a beam comprises rolling, in a longitudinally profiled rolling process, two flange pieces (6, 7), such that one surface (8) of each rolled flange piece is profiled according to a predetermined thickness profile; and joining (12, 13) the rolled flange pieces together via the profiled surfaces.
METHOD OF MANUFACTURING A BEAM

This invention relates to a method of manufacturing a beam, in particular for structural metal beams.

Universal beams also known as I-beams or H-beams are regularly used in building structures. However, the type of beam that is commonly used is not as efficient or optimised as it could be. Typically, the beams are of constant cross section along their length. The size of cross section is selected from a list of catalogue sizes and chosen based on the maximum bending moments and shear forces expected in use. There may be additional criteria such as buckling limits and allowances for holes. The size of the cross section is therefore based on the worst case condition along the length of the beam. However, in practice these sizing criteria do not apply to all points along the length of the beam, so at points along the beam the beam is over specified; it has excess material and excess weight that is not required.

One reason why the majority of universal beams have a constant cross section along their length is that most of these beams are rolled in universal beam rolling mills and the standard technology in this type of mill does not allow the beam cross section to be varied along the length of the beam.

Recently there have been various attempts to overcome this restriction. WO2012032301 describes apparatus and methods for rolling beams with variable depth, variable flange thickness, variable flange width etc. EP0756905 describes a related technology whose main purpose is to achieve consistent overall beam depth for different flange thicknesses. JP2000343102 describes another method of producing beams with variable web depth and flange thickness. These methods have several significant disadvantages. The main problem is that the material flow patterns involved in rolling a one piece beam with variable cross section along its length are very complex and it is difficult to achieve the correct material properties and to avoid undesirable curvature of the beam. Another issue is that new equipment is required.

To avoid the difficulties involved in rolling a beam with varying cross section along its length an alternative manufacturing method is to fabricate the beam; that is to construct the beam by welding or joining plates or sections together. The construction of
fabricated beams is well known, for example as described in US 18433 18, where arched beams are provided, or truss beams as illustrated in US 620,561, where the depth is modified by cutting material from the web and then joining the cut edges together. A characteristic of these beams is that the thickness of the material in the web and the flange is constant along the length of the beam. The only thing which changes along the length of the beam is its depth. Another well-known type of fabricated beam is the castellated or cellular beam although in general this construction is used to increase the beam depth relative to its parent section along the full length of the beam and not specifically to vary the section along the length of the beam. A significant disadvantage of these prior art fabricated beam designs is that because the web thickness and flange thickness are constant along the length of the beam the change in section can only be achieved by modifying the web depth or the flange width. Whilst changing the web depth or flange width is acceptable for some applications, in building applications it is preferable to have beams of constant depth and constant flange width to make the fitting of floor slabs, ceiling parts and walls simple.

In Fig. 5 of JP 2000343 102 a beam which changes section part of the way along its length is illustrated. This beam consists of two separate I-beams with different flange thicknesses, but with the same web depth welded together. It is clear that by welding several different I-beam sections together it would be possible to produce beams in which the cross section varies along the length, but this has several disadvantages. Firstly in order to approximate the varying load requirements along the length of the beam reasonably accurately a large number of different sections would be required and welding all of these sections together whilst maintaining the straightness of the beam would be difficult. Secondly the welds in the flanges of the beam would potentially weaken the beam.

Another method of producing a beam with the ideal variation in cross section along its length is to machine the beam out of either a solid bar or out of a beam which starts with a constant cross section along its length, equal to, or greater than the maximum cross section required. A related method is to fabricate the beam from plates or sections which have been machined to give variations in thickness along their length. However, these methods of manufacture are extremely wasteful of material and expensive and are
typically only used for beams in things like aircraft. They are not practical or cost
effective solutions for beams in building construction.

Another method of producing a beam with a variation in cross section along its
length is to fabricate the beam using longitudinally profiled (LP) plates. The rolling of LP
plates in which the thickness of the plate varies along the length of the plate is well
known and such plates are commonly used in shipbuilding and bridge building. Large I-
beams have been fabricated using longitudinally profiled plates as described by Schroter
in "Heavy steel plates for efficient constructional steelwork" and Richter and
Schmackpfeffer in "Longitudinally profiled plates cut costs". However, the application of
LP plates in the fabrication of I-beams has so far been limited to very large structures
such as bridges, power stations and very tall buildings. I-beams for general constructional
use in buildings still mostly use constant cross-sections. One of the reasons for this is that
the production of LP plates in which the thickness varies smoothly over the relatively
short length of a standard building I-beam has not been practical.

In accordance with a first aspect of the present invention a method of
manufacturing a beam comprises rolling, in a longitudinally profiled rolling process, two
flange pieces, such that one surface of each rolled flange piece is profiled according to a
predetermined thickness profile; and joining the rolled flange pieces together via the
profiled surfaces.

Preferably, the method further comprises rolling the flange pieces such that
another surface of each rolled flange piece is substantially flat.

The rolling process imparts a profile to one face of the flange piece, whilst
keeping the opposite surface flat, so that the beam has the required strength at various
points along its length without extra material and weight being used unnecessarily, as
well as having the convenience for the end user of a flat surface.

Preferably, the method further comprises rolling the two flange pieces together
and back to back.

Preferably, the rolled flange pieces comprise T shaped flange pieces.

Preferably, the flange surfaces of the manufactured beam remote from the web are
substantially flat and parallel.
In accordance with a second aspect of the present invention, a method of manufacturing a beam comprises rolling, in a longitudinally profiled rolling process, a flange piece, such that a plurality of surfaces of the rolled flange piece are profiled according to a predetermined thickness profile; wherein the longitudinally profiled rolling process comprises rolling Y-shaped sections; and finishing the Y-shaped sections to form T-shaped sections; and wherein the method further comprises joining two of the rolled flange pieces together via a profiled surface of each flange piece.

Preferably, the method further comprises providing a corresponding rolled web piece and joining the rolled flange pieces via the rolled web piece.

A profiled surface of each flange piece is joined to a correspondingly profiled surface of the web piece to join the two flange pieces together.

Preferably, the method further comprises manipulating one or more rolls during the rolling operation in order to vary individual beam dimensions along the beam length.

Preferably, the method further comprise casting raw material with at least part of the required thickness variation already present in the cast material and rolling the cast material.

The present invention provides a fabricated beam which is constructed from one or more LP plates with one flat side and one profiled side or from one or more T-sections in which the thickness of the flange part varies along the length of the beam, so that those parts at which higher forces are applied have additional material for strength and areas of relatively low loading have a reduced cross sectional area. It also provides for an apparatus to produce T-sections with varying thickness along their length. The invention is able to produce a beam with constant or almost constant depth and flange width, but with varying flange and web thickness along its length to satisfy the requirement of the building industry for beams of constant depth and constant flange width to make the fitting of floor slabs, ceiling parts and walls simple.

An example of a beam and a method of manufacturing a beam according to the present invention will now be described with reference to the accompanying drawings in which:

Figures 1a and 1b illustrate side view and cross section of a typical rolled universal beam;
Figure 2 illustrates roll gap view of conventional universal beam mill;

Figures 3a to 3c illustrate side view and cross section of a first example of a fabricated beam using LP profiled plate for the flanges.

Figures 4a to 4c illustrate the side view and cross sections of a second example of a fabricated beam using LP profiled plate for the web.

Figures 5a to 5d illustrate the side view and cross sections of a fabricated beam and a method of rolling the flanges of said beam using LP profiled plate with one flat side according to the present invention.

Figures 6a to 6d illustrate the rolling of a T-section part with varying flange thickness and construction of a fabricated beam according to the present invention;

Figure 7 illustrates an alternative method of rolling the T-section parts according to the present invention.

Figures 8a to 8c illustrate a roll gap view of an alternative mill configuration for rolling T-section parts according to the present invention;

In a conventional universal beam as illustrated in Figs. 1a and 1b, the beam 1 has a web 2 and flanges 3 at each end of the web. As can be seen from Fig. 1b, the thickness 4 of the flanges, the depth of the web 5b and the depth 5 of the beam is constant along the length of the beam. Since the cross section is constant and must meet the maximum load requirements along the length of the beam then at those points along the length at which the maximum loading is not experienced there is more material than is actually required.

Fig 2 illustrates the final rolling step in a conventional universal beam mill in which rolls 101, 103 roll the flanges exerting a roll force 105, 106, whilst rolls 102, 104 roll the web exerting a roll force 107, 108. In practice universal beam mills usually roll the I-beam on its side - as an H-beam - but the principle is the same as that illustrated in Fig 2.

The present invention provides a beam and methods of manufacturing a beam which enable the profile to be tailored to the loading requirements at each point along the beam, rather than using the maximum load requirement throughout. By continuously matching the section properties to the stress of the beam along its length, a mass reduction of the beam is possible. This is achieved by continuously determining the most
efficient cross section possible whilst satisfying all standards, codes & regulations throughout the length of the beam.

Recent developments such as those described in GB121301 1.8 make it possible to produce plates with multiple changes in thickness in the short length of a standard building I-beam and to efficiently produce these LP plates by shearing the as-rolled length into several shorter lengths each with a longitudinal profile. This makes it possible to construct fabricated beams for general building use in which the flange thickness or the web thickness or both vary along the length of the beam. However beams for general constructional use in buildings fabricated from LP plates still suffer from certain problems. One problem is that it is difficult to achieve a flat top and bottom face and constant beam depth with conventional LP plates. Another problem with fabricated beams constructed from LP plates is that the welds are situated at the interface or corner between the flanges and the web in areas of high stress and thus they potentially weaken the beam.

Fig 3 illustrates a fabricated beam constructed from LP plates for the flanges. The thickness variation along the length includes multiple points of inflection as described in GB121301 1.8. In typical applications the maximum loads in the beam are not at the ends of the beam, but in the centre and the minimum loads are not at the ends, but part way along the beam. A profile such as that which is illustrated in Figs. 3a to 3c optimises the beam cross section for this variation in the loads along the length. Fig 3a shows two LP plates for flanges 31, 32 and a plate for the web 33. In this example, the web is constant thickness, but it could also be manufactured from LP plate as well. In this example the web of the beam has been cut into a shape 36 to match the profiles of the flanges, although if the variation in flange thickness is not very large then this may not be necessary and a web piece with straight edges may be welded directly to the LP profiled flanges 31, 32. Welds 34, 35 which join the flanges and the web together are situated directly at the interface, or corner, between the web 33 and the flange 31, 32 and are thus in a highly stressed area of the beam. Top and bottom faces of the beam 37, 38 are not completely flat because LP rolled plates vary in thickness relative to their centreline.

With LP plates which are rolled as simple tapers as illustrated in Schroter and in Richter and Schmackpfeffer it is possible to achieve flat top and bottom faces, but with more
complex curved profiles it is not possible to get flat top and bottom faces unless the LP plates are specially straightened after rolling specifically to achieve one flat side. In practice some variation in the overall depth of the beam can be tolerated in building construction and so the LP plates would not always need to be straightened. However beams with large variations in flange thickness along their length would need to be straightened in order to remain with the required tolerances for the overall beam depth.

Figs. 4a to 4c illustrate an alternative fabricated beam construction according to the known prior art. A beam is constructed from two constant thickness flanges 18, 19 which are welded to a variable thickness LP rolled web 23. The web 23 varies between its thinnest part 22 and thickest part 21. Welds 12, 13 join the web to the flanges. This construction has the advantage over the construction in Fig 3 that the beam has constant overall depth without any straightening of the LP rolled plate. However this type of construction in which it is only the web thickness which changes along the length of the beam is not as efficient at minimising the weight of the beam as the type with variable flange thickness. Also this beam construction still suffers from the fact that the welds are in the corner between the web and the flange in a highly stressed area.

Combining the LP flanges illustrated in Fig 3 with the LP web illustrated in Fig 4 would still suffer from the same problems as the beam illustrated in Fig 3 in that the overall depth would vary along the length and the welds are in a highly stressed area.

Figs 5a to 5d illustrate a beam and a method of rolling the flanges of a beam according to one aspect of the present invention. In order to produce a beam with constant overall depth along its length, the flanges 6, 7 are produced with one flat surface 10 and one profiled surface 8, 11. Use of a longitudinally profiled rolling process results in the thickness of a plate being rolled varying along the length of the plate - in this case the plate being rolled forms the flanges of the beam and a profiled surface of the flange has a profile which varies in thickness along its length. According to one aspect of the present invention this is achieved by rolling with rolls 201, 202, the two flanges 6, 7 back to back as a pack with a separator layer or compound 51 between them as illustrated in Fig 5d. The use of separator compounds is well known in clad plate rolling for example.

After rolling, the two flanges 6, 7 are separated from each other. The flanges required for beams are usually much narrower than the width which a plate mill can roll and therefore
for the most efficient production the rolled pack has a width which is a multiple of the
required flange width. After rolling the plates are cut to the required flange width as
illustrated by the dashed lines 52. The flanges produced in this way have one side 8,
which is profiled and one side 10 which is substantially flat. When these flanges are
fabricated into a beam as illustrated in Fig 5c, by welding along the weld lines 12, 13 to a
correspondingly profiled web 9 of length 16 which has its deepest point 14 where the
flange is thinnest, the overall beam depth is substantially constant along the length of the
beam, whilst the flange thickness 15 varies along the length which is an improvement
over the example of Fig 3, although it still suffers from having the welds in a highly
stressed location.

Figs.6a to 6d illustrate the final stage of rolling of a T-shaped (T-section) part
according to a second embodiment of the present invention. The upper roll 60 has a
groove 54 which accommodates the stem of the T. The lower roll 52 does not have a
groove. By moving rolls 60, 52 closer to each other, or further apart from each other, the
thickness of the flange part of the T section may be varied along the length of the T
section as illustrated in Fig 6b. Due to the restraining effect of the stem careful guiding of
the T-section is required during rolling in order to keep it straight. When the thickness of
the flange part is changed this naturally tends to modify the height of the stem of the T as
well. One option for the manufacture of the beam is to cut the web part to fit the variation
in the height of the stem of the T but a simpler option is to cut the stem of the T at a
constant height as illustrated by the dashed line 53 in Fig 6b. This means that the web
part can have a constant depth and it makes construction of the beam simpler. The beam
constructed from two T-section parts 55, 56 with varying flange thicknesses and a web
part 57 has two welds 58, 59. These welds are located away from the corner between the
flange and the web and are thus less highly stressed than the welds in the beams in the
examples of Figs. 3 and 4.

An even simpler construction may be achieved if the T-sections are rolled with
sufficiently long stems that the required beam depth is achieved by simply welding the
two stems 55, 56 together with a single weld 501 as illustrated in Fig 6d. This has the
additional advantage that the weld is now in the ideal place which is on the neutral axis of
the beam. However rolling T-sections with varying flange thickness with long stems is
more difficult than rolling them with short stems because of the restraining effect of the stem.

Figure 7 illustrates an alternative method of rolling the T-section parts in which both upper roller 61 and lower roller 62 have grooves and two T-sections 67, 68 are rolled back to back with a separator compound or layer 66 between them. The use of separator compounds is well known in clad plate rolling for example. This method has the advantage that it is easier to achieve straight T-sections because the top and bottom bending forces during rolling balance each other out.

Figures 8a to 8c illustrate an alternative method of rolling the T-section parts for a beam according to the invention. The mill has three rolls 71, 72, 73 which can be moved closer to each other or further away from each other in order to vary the thickness of both the flange and the stem parts of the T-section. By analogy with the conventional beam rolling process, the step which is illustrated in Fig 8a is the intermediate rolling stage in which a Y-shape 79 is rolled. In the final rolling stage the Y-shape is passed through a finishing stand similar to that in Fig 6a in order to convert the Y-shape into a T-shape (T-section). The advantage of carrying out the intermediate rolling in a Y-shape is that it is easier to achieve large thickness changes in the flange whilst keeping the material straight. In general it is easier to achieve large thickness changes in the flange whilst keeping the material straight if the same ratio of thickness change is applied to the stem part. This is simple to achieve by adjusting the three rolls together. Consequently the mill illustrated in Fig 8a is capable of producing a Y-section which can be converted into a T-section which has both a long stem part and large thickness changes. A fabricated beam such as that illustrated in Fig 8b can then be made by welding 77 the two T-sections 75, 76 together. If the ratio of thickness change in the web part is made comparable to that in the flange part, then the web of the beam also has thickness variations along its length as illustrated in Fig 8c. If a separate web component is required in order to achieve the required overall beam depth as illustrated in Fig 6c, then the web part can either be rolled with matching thickness variations or it can have constant thickness. Fig 8c shows Fig.8b viewed from above and illustrates how the web thickness 78 and flange thickness both vary.
The sectional properties of a beam may be influenced by varying a number of
geometrical parameters. The parameters addressed according to the present invention are the flange thickness and the web thickness. This avoids complication of the design and construction process by maintaining the outer envelope dimensions of the beam, so that it can fit into any construction where a universal beam would have been used previously. The T-sections with varying flange thickness may also be used to fabricate beams with variations in beam depth along their length.

All aforementioned embodiments of the invention can be produced using standard raw material geometry i.e. billets and plates as the feedstock. The stages required and forces required by the invention can be reduced if variable cast materials are used at the start of the process. For example a T-section which has large variations in thickness along its length could be rolled from a cast product which already has some thickness variation along its length.

The examples of the present invention described above allow for implementation of a set of beam profiles tailored to particular applications, such as a specific office grid structure, which can be designed according to standard building codes and loading conditions. This means a final product can be manufactured as specified by the designer, rather than having to use standard products. For example, the beams can be tailored to a specific structure, or a specific position within that structure and a product specification for the beams can specify the working limits of the mill or workshop allowing more flexibility for the designer.

The invention has the benefit of maintaining parallel or almost parallel flange outer surfaces which are convenient for construction purposes, as well as reducing the total amount of metal used in the construction. In the case of the beams constructed from T-sections the invention has the additional benefit of moving the welds between the components away from the highly stressed areas of the beam. In each example, use of a longitudinally profiled rolling process results in a web or flange having a profile which varies in thickness along its length.
CLAIMS

1. A method of manufacturing a beam, the method comprising rolling, in a longitudinally profiled rolling process, two flange pieces, such that one surface of each rolled flange piece is profiled according to a predetermined thickness profile; and joining the rolled flange pieces together via the profiled surfaces.

2. A method according to claim 1, further comprising rolling the flange pieces such that another surface of each rolled flange piece is substantially flat.

3. A method according to claim 1 or claim 2, further comprising rolling the two flange pieces together and back to back.

4. A method according to any preceding claim, wherein the rolled flange pieces comprise T shaped flange pieces.

5. A method according to any preceding claim, wherein the flange surfaces of the manufactured beam remote from the web are substantially flat and parallel.

6. A method of manufacturing a beam, the method comprising rolling, in a longitudinally profiled rolling process, a flange piece, such that a plurality of surfaces of the rolled flange piece are profiled according to a predetermined thickness profile; wherein the longitudinally profiled rolling process comprises rolling Y-shaped sections; and finishing the Y-shaped sections to form T-shaped sections; and wherein the method further comprises joining two of the rolled flange pieces together via a profiled surface of each flange piece.

7. A method according to any preceding claim, wherein the method further comprises providing a corresponding rolled web piece and joining the rolled flange pieces via the rolled web piece.
8. A method according to any preceding claim, further comprising manipulating one or more rolls during the rolling operation in order to vary individual beam dimensions along the beam length.

9. A method according to any preceding claim, further comprising casting raw material with at least part of the required thickness variation already present in the cast material and rolling the cast material.
### A. Classification of Subject Matter

INV. B21B1/08 E04C3/06

According to International Patent Classification (IPC) or to both national classification and IPC

### B. Fields Searched

Minimum documentation searched (classification system followed by classification symbols)

B21B B21C B21H E04C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of database and, where practicable, search terms used)

EPO-Internal, WPI Data

### C. Documents Considered to be Relevant

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Further documents are listed in the continuation of Box C. [See patent family annex.]

* Special categories of cited documents:
  
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Date of the actual completion of the international search

26 March 2014

Date of mailing of the international search report

03/04/2014
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