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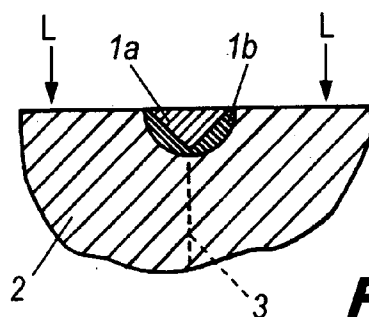


Fig. 1

(57) Abstract: Fracture formation of components such as connecting rods used in automotive engines is known. Material with sufficient strength is used to form the component and then through providing a notch and appropriate loading a brittle fracture is achieved. Prior systems have utilised broaching tools or drilling in order to create a notch to initiate fracture. By providing a continuous laser incident upon a base component in order to melt a proportion of the surface of the component a notch is created in accordance with aspects to the present invention. The melting process and heat sink effect of the bulk of the component results in phase transformations which provide an embrittled notch and therefore acts as a fracture initiation site. By appropriate choice of laser power, incident area and drill time in association with material type and base component dimensions particular transformations can occur in the notch (2). With regard to steel these features are intergranular cracking at columnar grain boundaries in the re-solidified zone, intergranular-cracking of coarse grains at locations where the austenitising temperature was high and solid state transformations to martensite.

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FRACTURE SITE FORMATION

The present invention relates to fracture site formation such as previously performed by notching and more particular to provision of fracture sites in components such as connecting rods utilised in internal combustion engines.

It will be appreciated that there are advantages with regard to some components formed by drop forging, sinter forging, powder forging and other processes. Through these processes robust components can be formed which can withstand high loadings. The example given of connecting rods relates to the components used in combustion engines to connect the crank shaft with the piston. Nevertheless, these components require subsequent machining and processing which can be difficult due to their hardness and toughness. One such processes relates to specific fracturing in order to create desired component designs. Fracturing the component has advantages in that close accurate component fitting can be maintained and mechanical interlocking achieved due to the rough fracture surfaces upon re-assembly whilst minimising machining operations.

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In order to assist the fracturing process it is necessary to create a crack initiating site previously achieved by a notch in the component. Traditionally this has been achieved through a broaching tool cutting or forming a groove at a crack initiation site. Unfortunately such broaching tools and associated expanding mandrels inherently suffer wear and therefore the efficiency of the initiation site in the form of a notch can vary. It will be appreciated ideally a broached initiation notch will have a sharp V shape to provide a stress concentration which will initiate the crack at the apex of the notch. After the connecting rods are split it may be necessary to machine the bearing bore in order to remove part ovality induced by the splitting process and to remove the notch from the bore. A shallower initiation notch will reduce the amount of post-fracture machining required to remove such a notch, and reduced bore ovality will also potentially reduce the amount of post-fracture machining.

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Alternative approaches include a pattern of using a laser beam with molten material blown away to leave a perforated surface along which crack initiation occurs. However, there is again variation in consistency due to laser maintenance and focussing problems.

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In some circumstances, and in particular with regard to connecting rods used in internal combustion engines, there is a desire to utilise cheaper and/or higher endurance materials. Traditional broaching tools as indicated have problems with respect to reproducibility of initiation. Wear requires replacement and maintenance over shorter time periods adding to costs and downtime.

In accordance with aspects to the present invention there is provided a method of producing a fracture initiation site in a component, the method comprising presenting a heat beam across an incident surface of the component and heat treating an incident portion of the component progressively along a site path with the heat beam chosen to have an incident area and power upon the surface to provide a desired size for the portion such that the remainder of the component acts as a heat sink for the incident portion to promote solid state transformations in the site.

Typically, the heat beam is a laser beam.

Preferably, the heat treating includes melting. Generally, the heat beam is continuously presented as the heat beam is moved progressively along the site path. Generally, the solidification and cooling in the solid state provides an embrittled hardened structure.

Typically, the solidified grains are directional. Generally, the directional grains are aligned in the initiation site. Possibly, the component is cooled on an opposite side to the incident portion to promote directionality in the

solidified grains. Possibly, the means of cooling moves for consistency with the heat beam upon the incident portion.

Generally, the incident area and power chosen for the heat beam will
5 depend upon the material from which the component is formed. Generally, the material is steel. Possibly, the steel has a carbon composition in the range 0.3 to 1.2 by weight % carbon. Generally, the portion or site undergoes solid state transformation and forms hard embrittled martensite. Alternatively, the material is cast iron.

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Generally, the incident portion containing the embrittled material has a depth chosen to provide a site having a substantially U shaped cross section. Possibly, the incident portion has a depth up to 1mm and typically is in the order of 0.45mm. Typically, the initiation site has a minimum depth in the
15 order of at least 0.07mm which has undergone melting and solidification. The remaining part of the site has received rapid heating and cooling in the solid state. In steels the minimum temperature to be reached to ensure the formation of martensite on rapid cooling is at least 700° C and typically it is substantially 720° C and above.

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Generally, the method is operated at ambient temperature. Generally, the method operates in an air atmosphere.

Generally, the heat beam is provided by a CO₂ or high power diode
25 laser or JAG laser but other lasers with appropriate power and focus may also carry out the method.

Typically, the heat input from the laser beam is chosen to provide shrinkage on solidification of the incident portion. Possibly, such shrinkage
30 provides cracking within the site upon solidification.

Typically, the laser beam is arranged to have a traverse speed across a component such that the laser beam traverses along the site path at a rate of about 0.5 metres per minute.

5 Possibly, to adjust the initiation site post formation processing is provided to vary the solidified and hardened grains configuration, size, hardness and/or orientation. Possibly, such processes include tempering and/or normalising. Possibly, such processing is arranged to substantially restore the component to that prior to presentation of the laser beam.

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Also in accordance with aspects to the present invention there is provided an apparatus for providing the above method.

Further in accordance with aspects of the present invention there is
15 provided a component including a fracture initiation site provided in accordance with the above method. Typically, the component is a connecting rod for an internal combustion engine.

An embodiment of aspects of the present invention will now be
20 described by way of example only with reference to the accompanying drawings in which:-

Figure 1 is a schematic cross section of a transformation notch in accordance
with aspects to the present invention;

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Figure 2 is a plan view of the transformation notch depicted in Figure 1;

Figure 3 is a schematic side cross section of a transformation process in
accordance with aspects of the present invention;

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Figure 4 is a plan view of the process as depicted in Figure 3 with the laser removed;

Figure 5 provides optical-microscope images of a fracture initiation site and a schematic representation of that site;

5 Figure 6 provides a scanning electron-microscope image of a fracture initiation site in accordance with aspects of the present invention;

Figure 7 provides scanning electron-microscope micrographs of fracture surfaces in accordance with aspects of the present invention;

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Figure 8 provides optical micrographs illustrating a fracture initiation site in accordance with aspects to the present invention after post formation, processing, tempering and normalising;

15 Figure 9 provides a graphic representation of modelled and measured depths of a laser phase transformation site and melted columnar zones using a fibre laser; and,

20 Figure 10 provides graphic illustrations of modelled and measured widths of a transformation notch and melted columnar zones using a fibre laser.

As indicated above, providing notches in metals such as steel in order to initiate fracture forming is a known technique. Such fracture forming is particularly useful in relation to splitting automotive engine connecting rods produced by drop forging or sinter forging. The fracture surfaces of the split
25 regions are then closely matched and allow accurate re-assembly. Unfortunately prior notching techniques which require material removal for production have disadvantages.

30 Aspects to the present invention utilise a heat beam such as a laser in order to provide a localised transformation as a fracture initiation site. This initiation site has been referred to in the description as a notch but it will be

appreciated contrary to the normal interpretation of a notch no material is removed in accordance with aspects of the present invention. Depending upon the laser heat beam process parameters used, the transformation notch created in the surface of a component undergoes either solid state transformations or a mixture of melting and solid state transformations. According to aspects of the present invention no material is necessarily removed in order to create a transformation notch but the material within the notch itself is transformed in order to provide a fracture initiation site. The depth and other parameters with regard to the transformation notch may be adjusted as well as the material phase and grain structure in order to achieve the most appropriate transformation notch.

Transformation notches in accordance with aspects of the present invention results in a reasonably sharp crack or fracture initiation due to a combination of formation of brittle martensite, inter-granular structures which include favourably orientated columnar grains after melting with inclusions and defects at their boundaries, inter-granular cracking of coarse grains produced by a high austenitising temperature and minor or major shrinkage cracks resulting in "centreline" cracking arising as a result of solidification shrinkage.

Lasers and other focused heat beams such as flames and arcs have previously been used for melting and/or solid state transformations in a number of metal processes including cutting, welding and surface treatments. In these processes the strength and toughness of the material is maintained or improved after laser treatment. Laser technology in accordance to aspects of the present invention is utilised to embrittle and thus initiate fracture within the component when required.

Figure 1 and Figure 2 schematically illustrate a typical transformation notch 1 formed in a base component material 2 using a laser. As can be seen the transformation notch 1 ideally has a wedge shape with an area of

transformation between the notch 1 and the base material 2 incorporating grain formation, phase changes and inclusions to facilitate notch fracture but practically is more rounded. The notch 1 initiates fracture which extends continuously across the base material 2 when a suitable load L is placed either side of the notch 1. Thus, a fracture is initiated which divides the component 2 along a fracture line 3.

Instead of removing material in order to create a notch as was a requirement with prior broaching and other known techniques aspects of the present invention retain that material within the notch 1 but in a phase transformed state in order to initiate fracture under load L. In such circumstances it will be appreciated difficulties with respect to contamination problems are reduced. It will also be appreciated that a laser in accordance with aspects to the present invention can form laser transformation notches 1 in accordance with aspects to the present invention at relatively high speeds. Typically a notch 1 according to aspects of the present invention can be produced in the order of 3 seconds plus transfer time. Prior broaching and laser scribing approaches where material is removed may take longer. The present invention changes the microstructure of the remaining material within the notch 1 by promoting solid state transformations as well as normally melting which act as a notch initiation site for fracture. Normally, the site or notch will be continuous along its length but it will be appreciated that sections of notch with small interruptions may be provided if necessary or desirable along the general direction of the notch. Such sections of the notch may be achieved by switching the laser beam on and off or deflecting the beam from continuous incidence upon the component surface.

It will be understood that the base component material 2 within which the notch 1 is formed is paramount to whether fracture will occur upon initiation. Ductile materials are inherently more difficult to fracture without plastic deformation which will result in mis-match between the fracture formed parts. It is necessary that both ductile and brittle materials which can be

fractured will also undergo the necessary melting and solid state transformations in order to create an appropriate transformation notch 1 in accordance with aspects of the present invention. An example of a material which may undergo notch formation in accordance with aspects of the present invention is steel C70S6 which is known to be used in relation to connecting rods for use in automotive engines. This steel has a composition as outlined below in table 1.

Table 1

10 *Chemical composition (wt %) of the as-forged C70S6 con-rod steel.*

C	Si	Mn	P	S	Cr	Mo	Ni	Fe
0.73	0.18	0.5	0.015	0.072	0.13	0.045	0.19	Balance

For the purpose of testing typically samples of such material in the order of 10mm by 10mm by 55mm are cut from a base material 2 across a notch 1 in accordance with aspects to the present invention. These samples are then appropriately processed in order to allow analysis with regard to phase transformations and other factors effecting fracture initiation.

In accordance with aspects of the present invention a continuous laser beam is presented to a base component material in order to transform a portion of the base component material along a notch path. This notch path will create the notch 1 as depicted in Figures 1 and 2. The presentation of the laser beam forms a transformation notch 1 as described previously whose depth and width vary dependent upon the presented laser beam size, power and transverse velocity which effects the dwell time of the laser incident upon the base component 2. The laser beam is presented to become incident on an incident portion of the component 2 to melt or at least cause solid state transformations in such portions as it progresses across the component to form the notch. Figures 3 and 4 provide schematic illustrations of a laser transformation in accordance with aspects to the present invention. As previously a base component 2 is formed from material which when subject to

a laser beam 4 melts in order to create a notch 1 which extends continuously across the base material 2. The laser beam effectively partially melts the material from which base component 2 is formed in order to create the transformed notch 1. In such circumstances dependent upon the laser beam size, power, and transverse velocity a pool of molten material (1a) moves across the component such a heat effected zone above 720°C are provided which then rapidly cools as a result of a heat sink effect by the remaining bulk of the material from which the base component 2 is formed.

Typically both CO₂ diode and JAG lasers along with fibre lasers can be utilised in order to create a notch in accordance to aspects of the present invention. The particular dimensions of the incident area upon the base component 2 can be varied dependent upon operational requirements. Typically with regard to a diode laser a notch track width in the order of 2mm will be provided. In accordance with aspects to the present invention formation of notches occurs with a laser beam in an air or other gaseous atmosphere whilst most of the component is at ambient temperature. Generally, prior to forming a site or notch in accordance with aspects to the present invention the base component 2 is cleaned to remove grease or other contaminates which may effect formation. However, it will also be understood that coatings may be applied to the component and these can either be utilised to enhance absorbability of the laser beam 4 or be removed as required.

Generally the notch track along which the laser beam passes in order to form a notch in accordance with aspects to the present invention will be straight. In such circumstances as depicted in Figures 3 and 4 the laser beam progresses in the direction of arrow heads X to form the notch 1 either by moving the beam or the component relative to the beam. The laser beam 4 partially melts the material from which the base component 2 is formed to a depth determined by operational requirements. It will be appreciated that this depth is relatively small and the bulk of the material from which the base

component 2 is formed will therefore act as a heat sink rapidly cooling the material in the current incident portion heated by the laser beam 4 in use. This cooling effect provides for solid state transformation as well as solidification in the notch 1.

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With regard to as-forged C70S6 steel it was found that martensite grains were formed post heating by the laser in accordance with aspects of the present invention. These martensite grains create the notch 1 in accordance with aspects of the present invention and can be distinguished from the bulk material from which the base component 2 is formed. With a CO₂ laser having a beam diameter of 1mm and operating at 1KW power transversing the C70S6 steel at differing speeds of 1 metre per minute, 2 metres per minute, 3 metres per minute, 4 metres per minute and 4.5 metres per minute it was found that the complete transformation notch depth respectively measured, 0.41mm, 0.35mm, 0.22mm, 0.08mm and 0.07mm. This notch depth comprises both the melted portion and the solid state transformation portion.

Figure 5(a) illustrates a cross section of a notch 11 formed at a translation speed of 4.5 metres per minute. With a CO₂ laser as can be seen the notch 11 consists of a single zone of solid state martensite transformation. However, as depicted in Figure 5(b) at slower transverse speeds that is to say 1 metre or 2 metres per second the samples of C70S6 steel showed a notch 21 which is characterised by columnar grains at an interface 22 between the notch 21 and the bulk of the component material 23 as well as a centreline crack 24. The formation of the columnar grains results from rapid heat extraction from the molten pool by the large volume of surrounding unheated bulk component material 23. The particular notch depicted in Figure 5(b) was produced by operating a Diode laser at 1.9Kw beam power with a translation speed of 0.5 metres per minute.

Figure 5(c) provides a schematic illustration of the notch 21 depicted in Figure 5(b). Thus, whilst a first zone 31 essentially comprises re-solidified material in the form of columnar grains containing martensite, a second zone 32 of component material has been transformed in the solid state to martensite in equiaxial grains in comparison with the remainder of the material 33 from which the component is formed which remains as pearlite and ferrite. In such circumstances the notch has a melt depth 34 with an overall notch depth 35 in order to create an initiation site for fracture. As can be seen rather than having a sharp V shape the notch is rounded. Notches in accordance with aspects of the present invention depend upon material transformation so that such roundness is less important.

The formation of the columnar grains as indicated above is as a result of rapid heat extraction from the molten pool by the larger volume of surrounding unheated material. The columnar grains tend to be aligned with the direction of heat extraction. The grains are directional.

Figure 6 provides micrographs in greater detail of a transformation notch with a solidified region in accordance with aspects to the present invention using a CO₂ laser operating at 1KW power with a traversing speed of 1 metre per minute.

In Figure 6(a) a re-solidified region 41 is shown which is distinct from a solid state transformation region 42 surrounded by original base component material 43. As shown in Figure 6(b) re-solidified directional columnar grains with inclusions 44 at intergranular grain boundaries are illustrated. The depiction in Figure 6(b) is taken at high magnification of the region 41 depicted in Figure 6(a). The columnar grains have an average width in the order of 7.5 micro metres. The orientation of the grains is determined by the direction of the laser beam passing across the surface and the direction of heat extraction through the bulk material 43 (Figure (6a)). It will be understood that particles of manganese sulphide (MnS) or otherwise as well as inclusions

and voids can be found or provided at the columnar grain boundaries to further enhance fracture initiation.

After re-solidification, the base material in region 41 continues to cool at a sufficiently high rate to transform in the solid state completely to martensite. Immediately below the solidified material a coarse austenitic grain size exists in the region 42 due to rapid grain growth at high temperatures as illustrated in the enlarged view Figure 6c taken from the region 42. The martensitic plates are larger in size than those in the coarse grains found in the remaining part of region 42 which is transformed to finer martensitic grains resulting from lower temperatures of austenitizing during laser treatment.

A boundary 45 between the transformation notch in accordance with aspects to the present invention and the base material 43 is shown in greater detail in Figure 6(d) as can be seen the boundary 45 comprises martensite/pearlite in a sharp demarcation between the base material 43, which has attained a eutectoid temperature typically in the order of 720°C for C70S6 steel, and that which did not. It will be noted that small partially dissolved pearlite regions can be observed illustrated by arrow 46 where thermal conditions were unable to fully austenize the base material.

It can be shown through hardness testing the hardness of the notch can increase from the order of 285Kg/mm² in the bulk material to over 800Kg/mm² in certain steels in the transformation notch. Little variation in hardness across the notch itself is identified because martensite is the only phase present other than the inclusions in both the re-solidified columnar grains as well as in the solid state transformed region. The small regions of incompletely dissolved pearlite come very close to the interface between the transformed martensitic region and the parent pearlitic region and have little effect on the abrupt change in hardness.

By analysis of the transformation notches it is found that three major factors effect fracture initiation. These factors are:-

- 5 (a) The intergranular cracking at columnar grain boundaries in the resolidified zone.
- (b) The intergranular cracking of coarse grains at locations where the austenitising temperature was high; and
- 10 (c) The transition to transgranular martensitic fracture, as illustrated in Figure 7(a) in which the specimen had a notch depth of 0.35mm.

With larger notches, that that is to say greater than 0.14 mm the
15 columnar grain regions fractured intergranularly as illustrated in Figure 7(b). Coarse equi-axed grains can be seen to fracture intergranularly at higher magnification as illustrated in Figure 7(c) close to the columnar boundary. The finer martensitic material below the coarse grains has undergone transgranular fracture as depicted in Figure 7(d) whilst finely distributed
20 inclusions can be observed at the columnar grain boundaries as illustrated in Figure 7(b). To summarise as depicted in Figure 7(a) a transformation notch having a 0.35 mm depth has an intergranular columnar zone 71 in a top portion, an intergranular equi-axed grain zone 72 in the middle and a transgranular layer 73 adjacent to the bulk material. As depicted in Figure 7(b)
25 with a 0.15 mm notch there is no columnar zone. As depicted in Figure 7(c) an intergranular zone 74 is illustrated at high magnification near a surface 75 of the notch depicted in Figure 7(b). Figure 7(d) illustrates an intergranular zone 76 at higher magnification than that depicted in Figure 7(a). As can be seen inclusions 77 are present. Figure 7(a) illustrates intergranular zones of
30 coarse martensite grains below the columnar grains as depicted in Figure 7(a). Figure 7(f) illustrates a transgranular martensitic region below the coarse grains as depicted in Figure 7(e).

It will be appreciated subsequent to notch fracture forming it is possible that other treatments may be applied to a component. Such treatments may include tempering and normalising, which will tend to reconvert the martensite grains and so restore the component to that prior to notch formation. This may be beneficial in that the component can be recovered rather than scrapped if the notch production process is not correct. Thus, avoiding waste and considerable expense with components formed from expensive materials and/or as a result of complex moulding or other forming processes.

The influence of tempering on a component for restoration can vary enormously dependent upon the transformation notch formed. With a deep notch such tempering is shown to have relatively minor effects which implies that the tough heat treated matrix has increased the fracture energy but by only a relatively small amount. However decreasing transformation notch size and more particularly the depth of the melted zone promotes a major increase in fracture energy required. This implies that embrittling features are maintained in the resolidified zone but their effect reduces with the zone depth. The tempered martensitic structure has its full effect when the melted zone reduces to zero with notch size.

Normalising a laser transformation notch produces a large change to both small and large notch sizes. With a large melted pool zone the fracture energy is raised. This implies re austenisation at 1000°C produces changes in the source of embrittlement. When the melted zone in the notch is small or non-existent then the normalising treatment effectively removes all embrittling mechanisms and restores the sample to resist fracture. Figure 8 comprises illustrations of optical images or cross sections of tempered (Figure 8a) and normalised (Figure 8b) samples. As can be seen in Figure 8a a visible notch region 81 is significantly reduced by the tempering treatment whilst normalising effectively removes the resolidification region produced during laser transformation. The melted pool zone in the normalised notch depicted

in Figure 8b remains despite changes in grain but has reduced fracture initiation responsiveness. This process may be brought about by a transformation to fine austenitic grains which subsequently on slow cooling has produced a fine grained pearlitic-ferritic structure which has effectively removed the aligned columnar grains. Such processes have therefore effected and removed the transformation notch in accordance with aspects of the present invention utilised to produce an initiation site for fracture.

In view of the above it will be appreciated that a laser beam of appropriate size, power and dwell time is presented to a component in order to create a transformation notch in accordance with aspects to the present invention. By appropriate choice of laser beam configuration, transformation notches can be provided particularly within carbon and alloyed steels which are probably as effective as the fatigue created sharp cracks usually employed to initiate brittle fracture for fracture toughness tests. In such circumstances without removing material transformation notches are created within a component to allow that component to be fractured as required as part of a manufacturing process.

In addition to molten and solid state transformations in the transformation notch it will be appreciated that solidification shrinkage will typically induce centreline cracking within the transformed notch. Such centreline cracking will again facilitate notch initiation of fracture of a component in use. It has been found that transformation notches of less than 0.4 mm depth typically do not induce any centreline cracking. Shrinkage induced centreline cracking is influential with regard to most fracture initiation with transformation notches of a depth less than 1.6 mm. However, it will also be understood that where no centreline cracking is provided notch brittle fracture can still occur although as will be appreciated such centreline cracking will contribute to ease of fracture initiation.

Fracture in the absence of centreline cracking is typically influenced by microstructural features as indicated such as the presence of carbon martensite throughout the transformation notch, aligned columnar grains with associated inclusions and impurities and other defects and the presence of coarse grains at the surface or the edge of the melted zone. It will also be appreciated that aligned columnar grains and the presence of coarse grains will further encourage intergranular features.

With C70 steel with a depth of notch less than 0.12 mm, that is to say with low heat input from incident laser beam, no melting takes place. In the zone where heating above the eutectoid temperature has occurred the resultant austenite transforms rapidly to martensite on cooling by the bulk of the sample to create the transformations desirable in accordance with aspects to the present invention for notch initiation. At the surface of the component the laser will typically promote high austenitising temperatures and therefore grain growth. The fracture energy associated with shallow martensitic cracks rapidly falls indicating the potential of the martensitic layers and the surface layer of coarse grains in the example of 0.7wt/% carbon steel to initiate a brittle crack fracture. Beyond a martensitic notch depth of 0.12 mm, the heat input leads to melting and the introduction of another embrittling mechanism that is to say aligned columnar grains which also rapidly cool to form martensite. Fracture energy decreases further with transformation notch depths greater than 0.4 mm in the specific example given here as there are all four embrittling mechanisms at work, namely centreline cracking, columnar grains, coarse grains and brittle martensite. The coarse grain region continues to form in notches deeper than 0.12 mm at the edge of the melted zone. Typically by considering these embrittling mechanisms and presenting an appropriate laser beam configuration in terms of power, incident area and dwell time an appropriate transformation notch in accordance with aspects of the present invention can be provided for fracture initiation.

As indicated above by use of a laser beam to create a transformation notch in accordance with aspects of the present invention it is possible to form components with more reproducibility than prior systems including broaching. It will be appreciated that the broaching tool will wear and therefore the sharp notch created will alter with time whilst a laser utilised in accordance with aspects of the present invention is repeatable. Laser transformation notching in accordance with aspects to the present invention can result in components which require less impact energy in comparison with mechanically notched components. Laser transformation notching generally is an improvement on mechanical broaching processes for fracture splitting of such components as connecting rods for automobiles and provides a more consistent result in comparison with broaching tools and other components which wear and/or require periodic sharpening. Analysis of fracture mechanics based upon a sharp fatigue notch and comparison with transformation notches in accordance with aspects of the present invention with respect to carbon steels has indicated that transformation notches in accordance with aspects of the present invention typically require a reduced crack initiation force, which leads to a reduced level of deformation of the notch component and a corresponding reduction in the amount of post-fracture machinery required.

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As indicated above laser beam configuration and power for a desired transformation notch will be dependent upon the material in which the transformation notch is to be formed and other operational requirements. Thus, specific combinations of laser power and transverse speed across the component surface to induce the necessary heat input and transformation depth will be chosen as required to achieve the desired solid state transformation to martensite and melting. It will be understood that the base component dimensions are also important with respect to the heat sink effect rapidly cooling the transformations achieved by the heating presented through the laser beam. It is important that the bulk of the component is relatively massive in order to achieve such heat dissipation for transformation in accordance with aspects of the present invention. In smaller components

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forced cooling could be achieved by external means. An important aspect with regard to achieving reduced fracture energies and eliminating deformation problems is by creating martensite formation and intergranular cracking of aligned columnar and coarse equi-axed grains when a molten zone is formed and then rapidly cooled in that molten zone through the heat dissipation effects into the bulk of the base component.

Both micro cracking and macro cracking can be associated with the molten zone producing centreline cracking due to solidification contraction. Such cracking when present in a large transformation notch can also reduce necessary fracture initiation energy.

Although described with regard to carbon and alloyed steels it will be appreciated that aspects to the present invention may be utilised with regard to forming transformation notches in a wide range of materials including cast iron and other relatively brittle materials. The transformation notch as indicated acts as an initiation site for fracture with the presence of brittle material. Generally the transformation notch will be of a limited depth and sufficient to achieve the fracture initiation requirements. Material will not be removed such that problems with respect to contamination are not present and the notch created through the phase transformations is utilised in initiating fracture.

As indicated above, configuration and power for the laser beam providing heating of an incident portion of the component is important such that there is heat transfer to create a molten zone or pool. Such heat transfer can be analysed using a suitably modified version of the Carslaw -Jaeger solution to the general heat conduction equation.

$$T_{(0,0,z,t)} - T_0 = \frac{2q^* (\alpha t)^{0.5}}{\lambda} \left[\operatorname{ierfc} \frac{z}{2(\alpha t)^{0.5}} - \operatorname{ierfc} \frac{(z^2 + a^2)^{0.5}}{2(\alpha t)^{0.5}} \right]$$

Where

$$ierfc(w) = \int_w^{\infty} erfc(\xi) d\xi = \frac{1}{\sqrt{\pi}} e^{-w^2} - w \cdot erfc(w)$$

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It will be understood that the modified Carslow – Jaeger solution takes account of heat diffusion parallel to and perpendicular to the steel component surface in the example steel. Resultant heating and cooling patterns from the movement of the laser beam across the component surface produces a phase transformation zone which can act as a notch for initiating fracture of the component section. The depth and width of the laser transformation notch can be calculated from a computer program utilising the modified Carslow – Jaeger equation given above. Figures 9 and 10 respectively provide graphic representations of modelled and measured depths of laser phase transformation notch and melted columnar zones utilising a fibre laser traversing a steel surface and modelled and measured widths of total transformation notch and melted columnar zones produced by a fibre laser traversing a steel surface. The fibre laser gave a 0.33 mm beam diameter with a 300W power beam. As can be seen there is substantial similarity between the measured results and model results given from the modified Carslow – Jaeger equation.

25

In the above circumstances as indicated previously the laser type, beam configuration and traverse speed are all important with regard to achieving the desired transformation notch for initiation of notch fracture in a component.

30

Whilst endeavoring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any

patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

CLAIMS

1. A method of producing a fracture initiation site in a component, the
5 method comprising presenting a heat beam across an incident surface of the
component and heat treating an incident portion of the component
progressively along a site path and the heat beam chosen to have an incident
area and power upon the surface to provide a desired size for the incident
portion such that the remainder of the component acts as a heat sink for the
10 incident portion to promote solid state transformations in the site.
2. A method as claimed in claim 1 wherein heat treating includes melting.
3. A method as claimed in claim 1 or claim 2 wherein the solidification and
15 cooling in the solid state provides a micro-structure which is susceptible to
crack initiation.
4. A method as claimed in claim 3 wherein the solidified grains are
directional.
20
5. A method as claimed in claim 4 wherein the material surrounding the
site acting as a heat sink orientates the growth of the directional grains so
they are aligned parallel to the required direction in the initiation site.
- 25 6. A method as claimed in any preceding claim wherein the component is
cooled on an opposite side to the incident portion to promote directionality in
the solidified grains.
7. A method as claimed in claim 6 wherein the means of cooling moves to
30 remain consistent with the incident portion.

8. A method as claimed in any preceding claim wherein the incident area and power chosen for the heat beam will depend upon the material from which the component is formed.

5 9. A method as claimed in claim 8 wherein the material is steel.

10. A method as claimed in claim 9 wherein the steel has a carbon composition in the range 0.3 to 1.2 weight % carbon.

10 11. A method as claimed in claim 9 or claim 10 wherein the incident portion or site upon solidification and cooling in the solid state forms hard embrittled martensite.

15 12. A method as claimed in any of claims 1 to 8 wherein the material is cast iron.

20 13. A method as claimed in any preceding claim wherein the incident portion has a depth chosen to provide a site having a substantially U cross-section.

14. A method as claimed in claim 13 wherein the incident portion has a depth up to 1mm.

25 15. A method as claimed in any preceding claim wherein the site has a minimum depth in the order of at least 0.07mm upon solidification, which has undergone melting then solidification whilst the remainder of the site has cooled in the solid state.

30 16. A method as claimed in claim 9 and any claim dependent thereon wherein the minimum temperature reached in the incident portion is 700° C and typically substantially 720° C and above.

17. A method as claimed in any preceding claim wherein the method is operated such that the remainder of the component is substantially at ambient temperature away from the incident portion.

5 18. A method as claimed in any preceding claim wherein the method operates in an air or other gaseous atmosphere.

10 19. A method as claimed in any preceding claim wherein the method includes possible post initiation formation site component processing to restore the component by reversing the effects of solidification and cooling in the solid state in the site.

20. A method as claimed in claim 19 wherein component processing includes tempering and/or normalising of the component.

15

21. A method as claimed in any preceding claim wherein the heat beam is provided by a CO₂ or a diode laser or fibre laser or JAG laser, or any other suitable laser.

20 22. A method as claimed in any preceding claim wherein the heat input from the heat beam is chosen to provide shrinkage on solidification of the incident portion.

25 23. A method as claimed in claim 22 wherein such shrinkage provides cracking within the notch upon solidification.

24. A method as claimed in any preceding claim wherein the laser beam is arranged to have a traverse speed across a component such that the heat beam traverses along the site path at a rate of at least 0.5 metres per minute.

30

25. A method of producing a fracture initiation site in a component substantially as hereinbefore described with reference to the accompanying drawings.

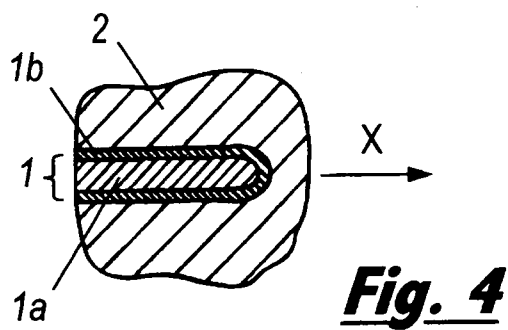
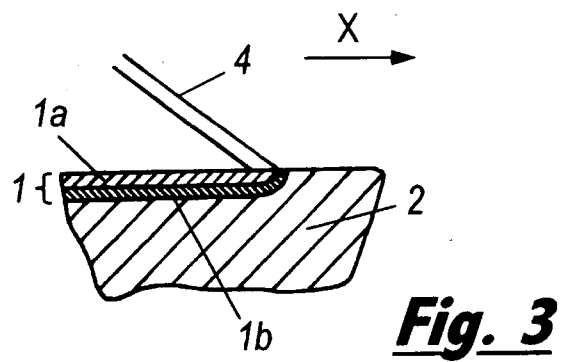
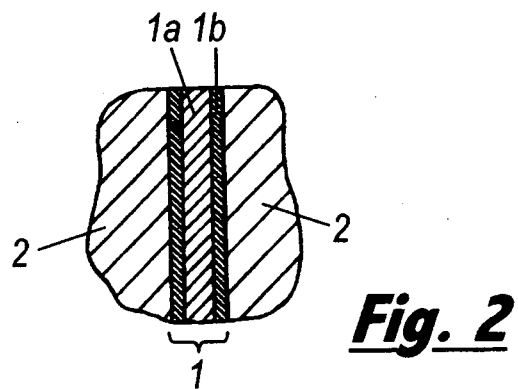
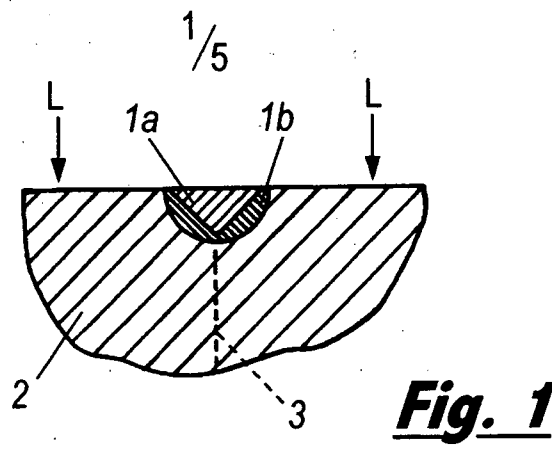
5 26. An apparatus for providing a method as claimed in any preceding claim.

27. An apparatus for providing a fracture initiation site in a component substantially as hereinbefore described above with reference to the
10 accompanying drawings.

28. A component incorporating an fracture initiation site formed in accordance with a method as claimed in any of claims 1 to 25.

15 29. A component as claimed in claim 28 wherein the component is a connecting rod for an internal combustion engine where there is a fracture initiation site in accordance with any of claims 1 to 25.

20 30. Any novel subject matter or combination including novel subject matter disclosed herein, whether or not within the scope of or relating to the same invention as any of the preceding claims.



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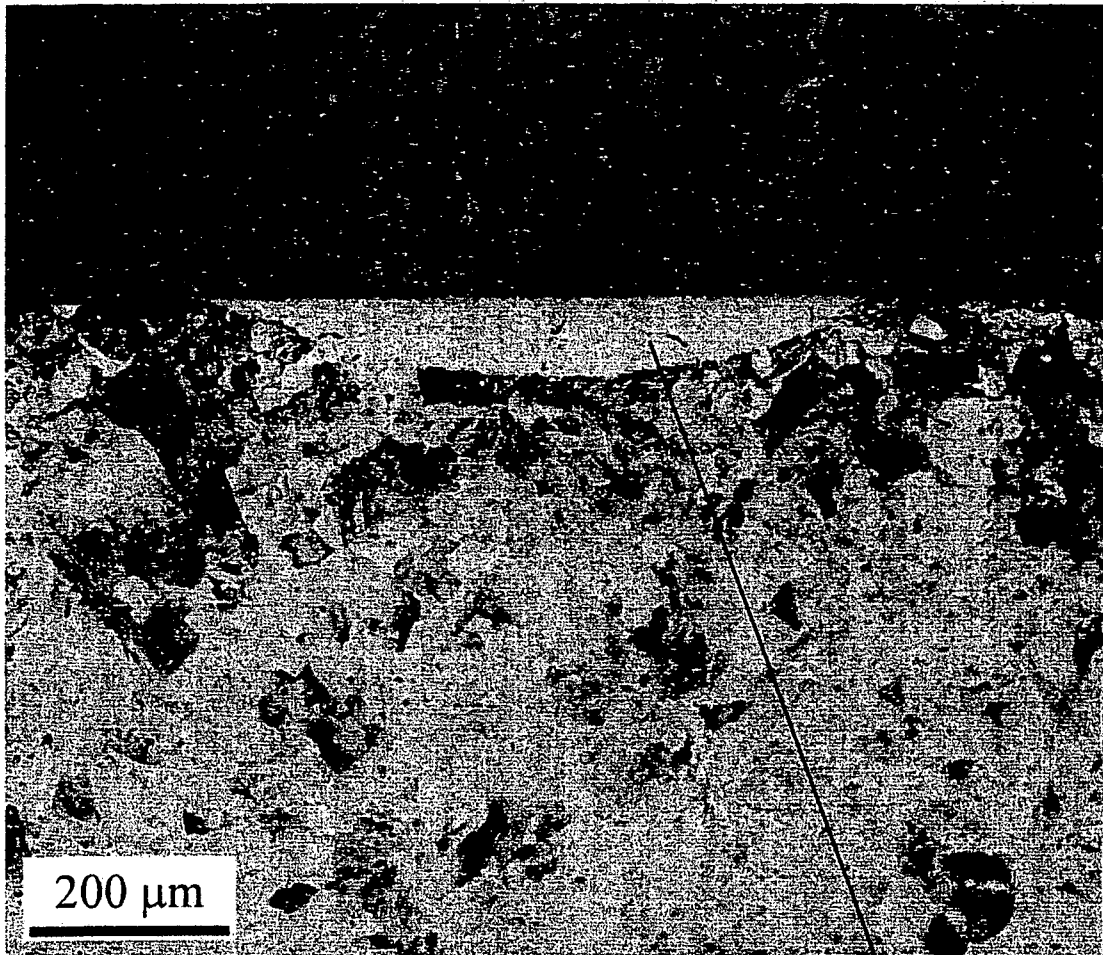


Fig. 5(a)

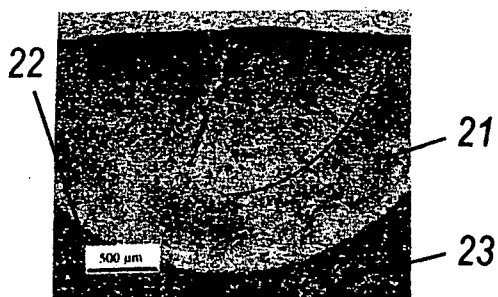


Fig. 5(b)

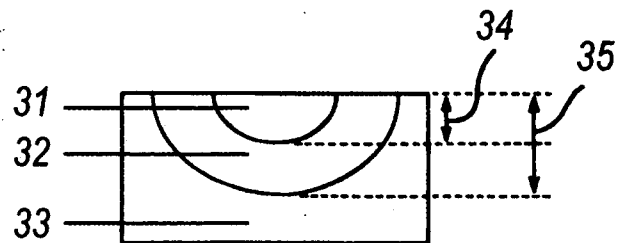


Fig. 5(c)

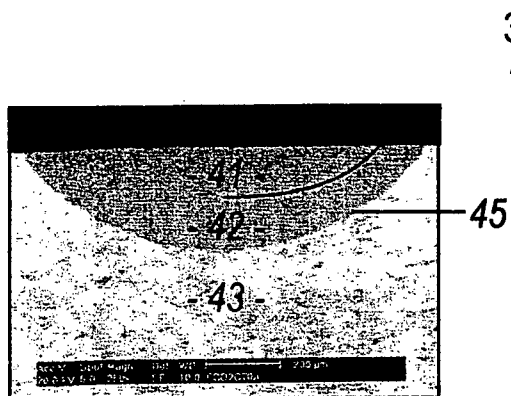


Fig. 6(a)

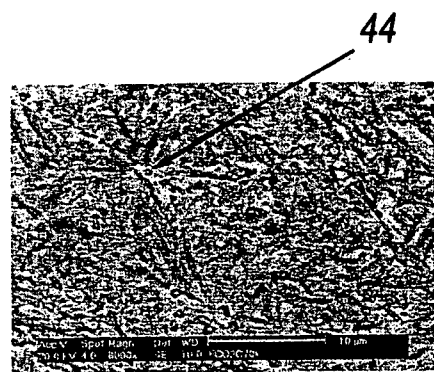


Fig. 6(b)

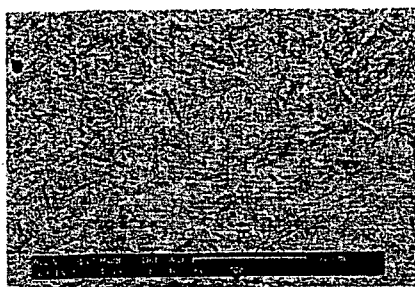


Fig. 6(c)



Fig. 6(d)

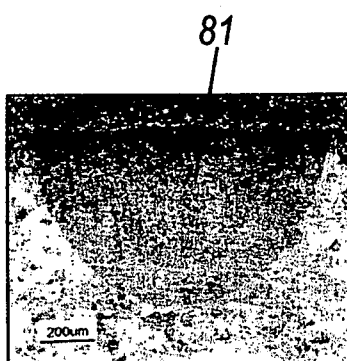


Fig. 8(a)

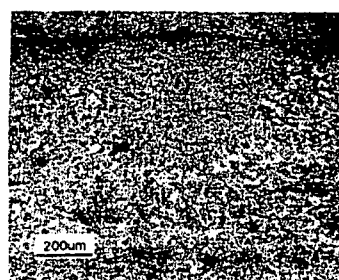
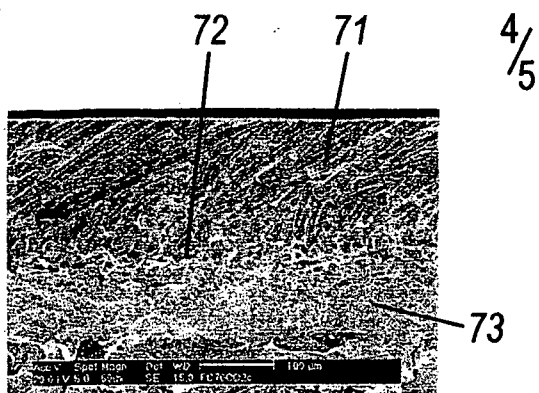
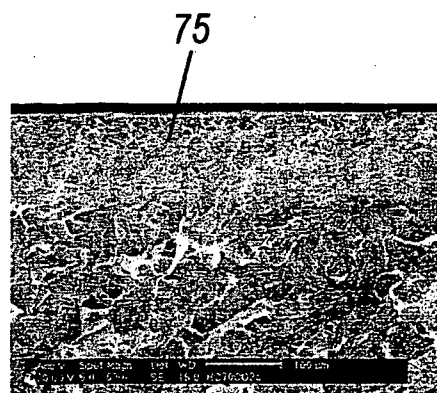
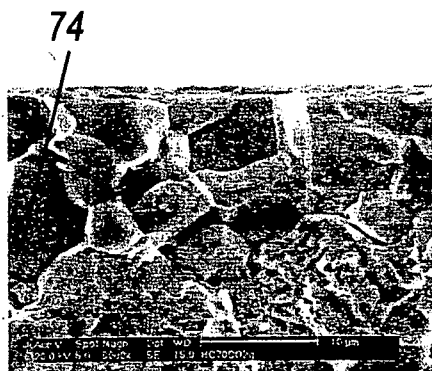
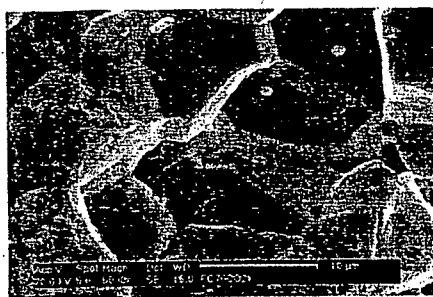
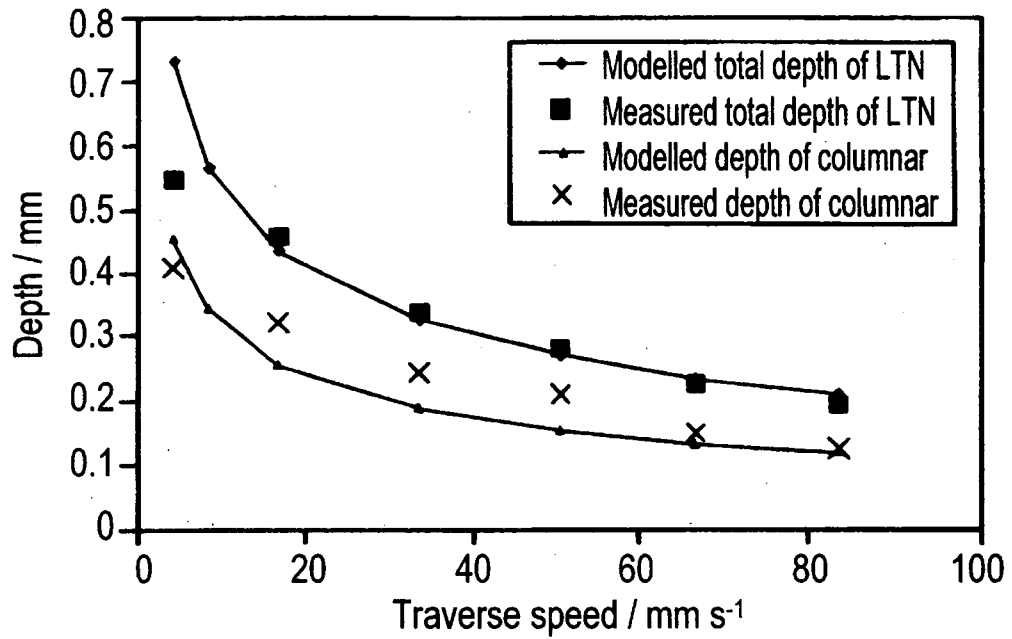
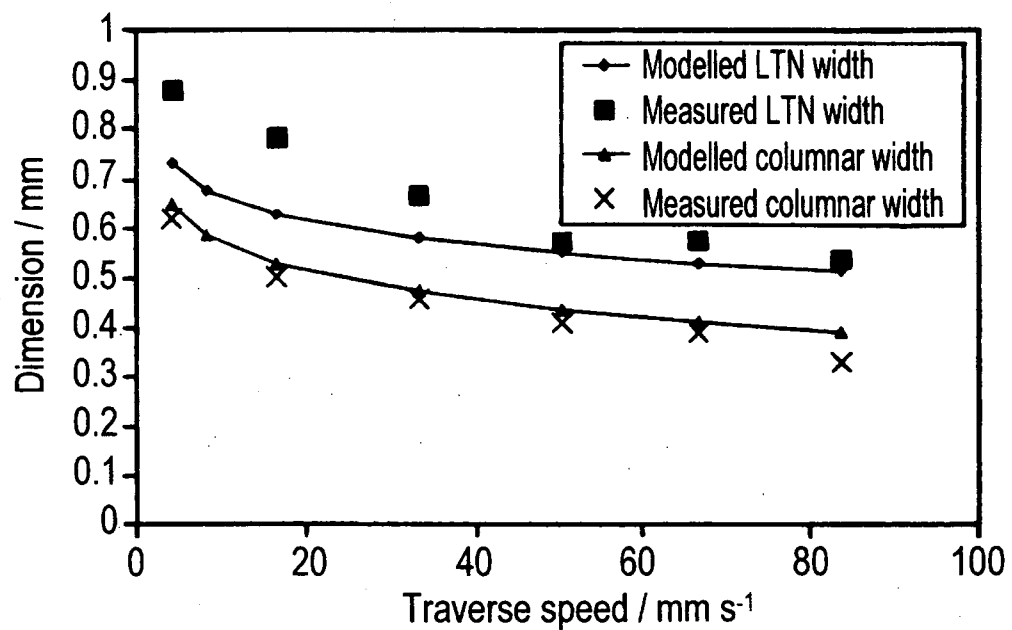


Fig. 8(b)

**Fig. 7(a)****Fig. 7(b)****Fig. 7(c)****Fig. 7(d)****Fig. 7(e)****Fig. 7(f)**

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**Fig. 9****Fig. 10**

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/001381

A. CLASSIFICATION OF SUBJECT MATTER

INV. F16C9/04

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)

B23K F16C B26F B23D

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 96/24458 A (MAUSER WERKE OBERNDORF MASCHIN [DE]; HOFMANN GERHARD [DE]; GRUHLER SIE) 15 August 1996 (1996-08-15) claims 1,10,18,22-27 page 10, line 20 - line 35 -----	1-30
X	WO 2005/103513 A (HONDA MOTOR CO LTD [JP]; MINEMURA KAZUO [JP]; MOMOSE YASUO [JP]) 3 November 2005 (2005-11-03) abstract figures 1-6 -----	1-30
X	EP 1 243 665 A (DAIDO STEEL COMPANY LTD [JP]; NISSAN MOTOR [JP]) 25 September 2002 (2002-09-25) abstract paragraphs [0041], [0042]; claims 4,5 ----- -/--	1

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

14 July 2008

Date of mailing of the international search report

22/07/2008

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Gavriliu, Alexandru

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/001381

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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International application No

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