

Feb. 9, 1971

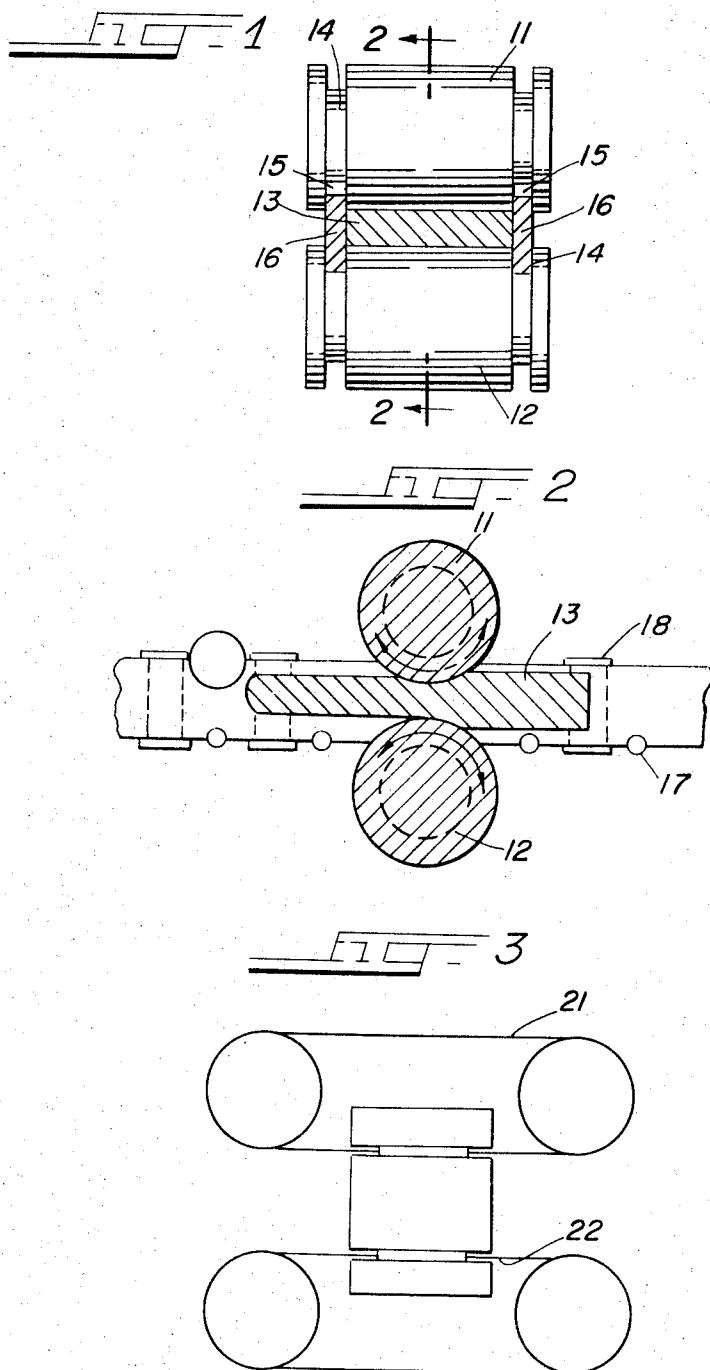
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3,561,240

METHOD AND APPARATUS FOR TREATING MATERIALS

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3 Sheets-Sheet 1



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METHOD AND APPARATUS FOR TREATING MATERIALS

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FIG. 5

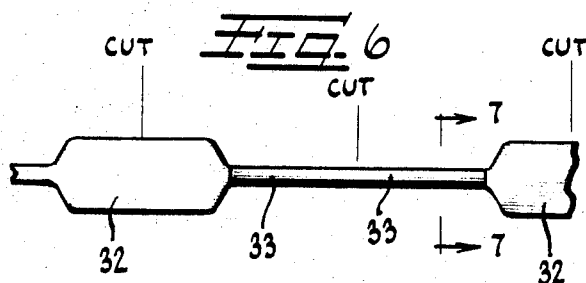
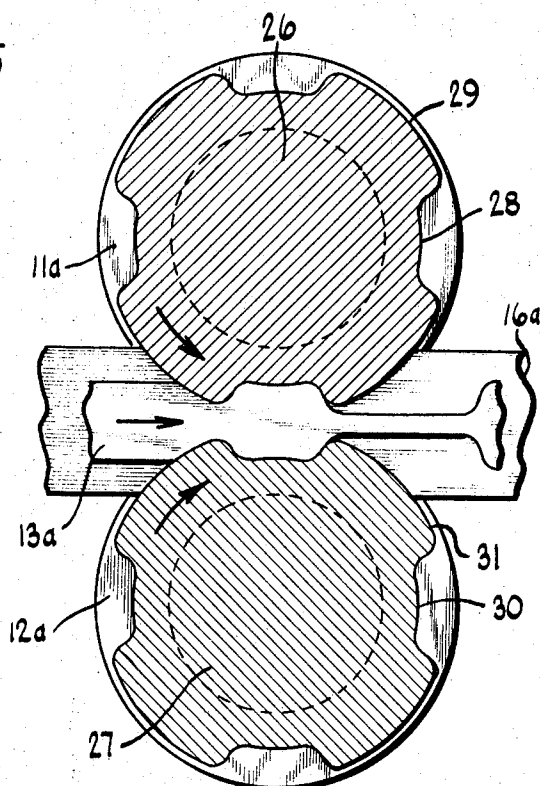
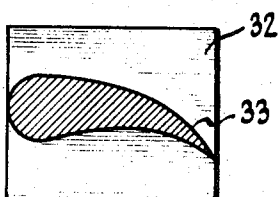


FIG. 7



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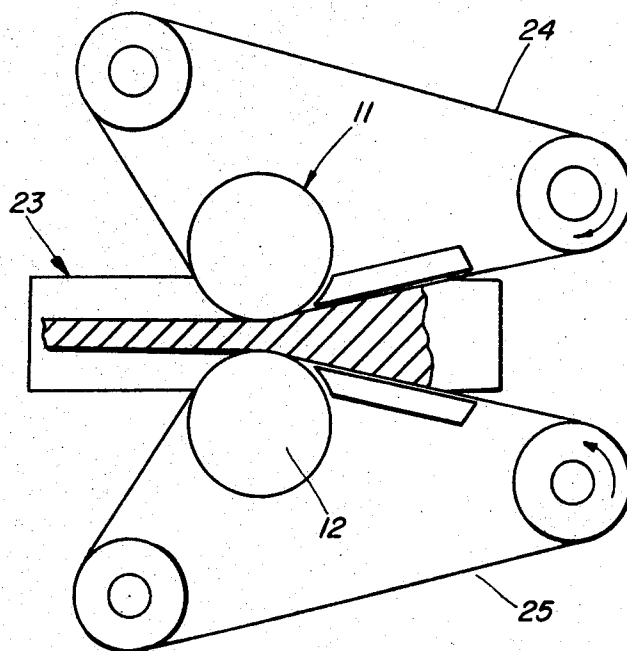
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METHOD AND APPARATUS FOR TREATING MATERIALS

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FIG. 4



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3,561,240 METHOD AND APPARATUS FOR TREATING MATERIALS

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Continuation-in-part of application Ser. No. 587,358, Sept. 16, 1966, which is a continuation-in-part of application Ser. No. 444,637, Apr. 1, 1965. This application Dec. 7, 1967, Ser. No. 691,109
Int. Cl. B21b 1/22, 39/00

U.S. Cl. 72—184

9 Claims

ABSTRACT OF THE DISCLOSURE

A method and apparatus is disclosed for forming materials into desired shapes by rolling or casting. The rolled shapes may be of constant or irregular cross section. The apparatus includes lateral restraint members that move with the workpiece to prevent edge cracking in rolling or provide a moving wall die in casting.

This application is a continuation-in-part of my copending application Ser. No. 587,358, filed Sept. 16, 1966, which application is a continuation-in-part of my application Ser. No. 444,637, filed Apr. 1, 1965, and now abandoned.

The present invention relates to a novel process and apparatus useful therewith for the rolling or casting of various materials and more particularly is directed to a relatively simple means of preventing edge cracking in the rolling aspect hereof. While my invention may be used with a number of materials which are subject to edge cracking upon rolling it has special applicability for the treatment of metals and furthermore my invention is useful in the continuous casting of metal ingots.

My invention is useful not only in the rolling and casting of materials such as metal sheets, slabs and plates, but also may readily be employed in the consolidation of metal powders into an integral body.

The essential feature of the rolling aspect of my invention involves rolling under complete lateral restraint with the lateral restraining members moving with the rolls and by employing such restraint I have discovered that I can readily and conveniently roll without producing edge cracking in those materials which hitherto, to the best of my knowledge, have never been rolled without edge cracking. The utility and importance of such discovery will be immediately apparent to those skilled in this particular art.

Another aspect of this invention is directed to the continuous casting of molten metal or the like into solid ingots by use of only slightly modified apparatus from that which is used in the edge restraint rolling embodiment hereof. As is well known to those skilled in this art molds which have previously been used in the continuous casting of materials, particularly metals, are usually made in the form of a cooled frame which is oscillated and/or critically lubricated to provide the means for separating the cast ingot from the mold. In some prior art processes the mold moves; in others water cooled drums or rolls are used to cast thin bands; another process employs a grooved wheel with a cover band for casting wire bars.

All of such prior art continuous casting processes suffer a number of disadvantages. Internal porosity and surface defects are common in all of the resulting cast materials except those made with the water cooled drums and the latter process yields materials of limited thickness due primarily to the failure to enclose the roll gap from the sides.

In distinction to these problems encountered in prior

art continuous casting methods, the present process provides excellent continuously cast ingots without any severe size limitations. All of this will be set out in greater detail as the description proceeds.

Accordingly, a primary object of my invention is to provide a method of preventing edge cracking during the rolling of metal structures which process includes as its most important step edge restraint at the sides of the material being rolled and which edge restraint members are movable with the rolling mechanisms.

Another object of my invention is to provide a material rolling process whereby edge cracking is markedly reduced or eliminated.

Still a further object of my invention is to provide a method and apparatus for the rolling of nonuniform cross sections under lateral restraint.

Another object of my invention is to provide apparatus for use in the present process.

These and other objects, features and advantages of my invention will become apparent to those skilled in this particular art from the following detailed disclosure thereof and the accompanying drawings in which:

FIG. 1 schematically illustrates a roll element for use in the present process;

FIG. 2 is a view taken along lines 2—2 of FIG. 1 in partial section and also schematically illustrates the practice of the present process and the equipment required herewith;

FIG. 3 schematically illustrates another embodiment of the process and apparatus of the present invention; and

FIG. 4 schematically illustrates still another embodiment hereof especially useful in the rolling of powder materials; and

FIG. 5 illustrates another embodiment of the present invention in partial cross section as in FIG. 2; and

FIG. 6 shows a product produced by the apparatus of FIG. 5; and

FIG. 7 is an enlarged cross section taken along line 7—7 of FIG. 6.

Before considering the present invention, reference should first be briefly had to the edge cracking problems encountered in the rolling of metal bodies as taught by the practices of the art prior to my invention. Obviously the rolling of flat slabs or sheets of metal has been carried out for a long time. Present industrial practices are a culmination of almost a century of effort and development in metal rolling and metal rolling techniques, but to the best of my knowledge until the present invention was made one of the most vexing problems faced by those operating in this area of technology, namely edge cracking, had not really been solved. Efforts directed to the elimination of edge cracking have been made but I know of no comparable process which either completely eliminates edge cracking or so markedly reduces such phenomena as results from the practice of edge restraint rolling as is taught in the present specification.

Others have attempted to alleviate this problem by, for example, rolling in grooved rolls or by the employment of vertical edge rollers. Neither of these processes have brought about any degree of improvement akin to my findings in the process herein described. As a result, edge cracking in crack-sensitive materials remains a serious problem and scrap losses due to edge cracking account for a substantial portion of the present production costs of some of the newer so-called "exotic" materials. In fact many materials with desirable mechanical properties have had to be somewhat abandoned because of their uncontrollable edge cracking or in the alternative, had to be produced by expensive methods in order to break down their cast structure. A similar situation has existed in the compaction of metal powders.

While the term "edge cracking" is self explanatory I merely wish to say at this point that it alludes to the cracking, splitting, breaking of a metal structure during rolling at the uncovered lateral sides thereof. As used in the present specification and claims the term also refers to similar detrimental phenomena occurring in materials other than metals. It appears that edge cracking is caused by secondary tensile stresses which are inevitable whenever metal or other material spread occurs as in rolling. The result has been with many materials that either they can not be rolled at all or there was a considerable loss involved in trimming the cracked portions off of the central body of the rolled material. The economic loss has been significant.

It has been perhaps recognized that edge cracking can be prevented only by the complete elimination of spread in the roll gap but prior to my present invention no workable solutions for this problem existed. The most widely practiced partial remedy is rolling in closed passes. Such passes are closed by interlocking annular projections (i.e., shoulders or the like) of the rolls. Such solution suffers from several limitations: The slab may be entered into the closed pass only at a substantially narrower width for otherwise the spreading material will firmly wedge between the shoulders of the roll and instead of being released at the exit side it will be wound around the roll. It is therefore common practice to allow almost free spread in the closed pass with consequent edge cracking of sensitive materials. In the rolling of powders the problem may be somewhat alleviated by placing one shoulder on each of the opposite rolls as disclosed in the patent to Naeser, U.S. 3,019,487, and Dasher et al., U.S. Pat. 3,017,665, thereby imparting a twist on the exiting strip product and freeing it from the confines of the roll gap. Such solution, however, is obviously unworkable with solid material having full density especially when such material has a substantial thickness. Furthermore, a three dimensional consideration of the problem will show that edge restraint in closed passes can be provided only if the shoulders of the rolls are big enough to cover the entire zone of deformation; the requisite large shoulders produce a substantial annular velocity difference between the rolled material and various parts of the closed pass with a resulting undesirable distortion and wear. Furthermore, it is impossible to reintroduce the material rolled in a closed pass into the same pass for further reduction and the heavy total reduction normally sought for can be achieved only in a succession of closed passes which for the reasons noted above must be successively widened thus opening the way for further edge cracking.

The edge cracking problems in rolling are substantially completely eliminated by the practice of my invention. By complete edge restraint laterally at right angles to the material being rolled edge cracking is substantially or completely eliminated in the rolling of most metals and other materials subject to edge cracking. It is important in the practice of such edge restraint that the lateral restraining members be movable with the rolls and with the material being rolled.

To understand my invention reference should next be had to FIGS. 1 and 2 hereof. Here is illustrated a two-high rolling mill having a top roll 11 and a bottom roll 12. A metal slab 13 being rolled is interposed between the rolls in the usual manner. Grooves 14 are provided in the rolls, said grooves being in register for both the top and bottom roll and as shown in the drawing, are lateral to the central part of the roll. In the two lateral grooves I insert a pair of restraining bars 16. It is such restraining bars 16 in this embodiment of my invention which provide the edge restraint of the material being rolled. The restraining bars are made of various strong materials, e.g., alloys similar to those of which the rolls are fabricated; therefore, as in the case of the rolls, they are

relatively incompressible compared to the material being rolled.

As clearly shown in FIG. 1 the rolled slab 13 is now rolled in a tightly closed, i.e., vertically and horizontally closed, chamber which not only provides the usual rolling but also tight and strong edge restraint.

Parenthetically, while a solid metal slab is illustrated in FIGS. 1 and 2 it will of course be apparent that metal powders may be substituted therefor and compacted and consolidated in the present process. Various other materials subject to edge cracking upon rolling may be similarly treated.

The restraining bars 16 closely but movably fit in the grooves 14 of the upper and lower rollers and thus their movement laterally is restrained. As shown in FIG. 1 each such restraining bar rests in the bottom of the groove provided in the lower roll and there is a space 15 left for clearance purposes between the top of the restraining bar and the top of the groove of the top roll 11. But because of such grooving the restraining bars 16 are held in close restraint to prevent lateral movement. The clearance 15 permits repeated thickness reductions of the slab being rolled by closing the rolls in the usual manner.

As shown in FIG. 2 the restraining bars are positioned on table rollers 17 and are assisted in being maintained in operative position by guide rollers 18.

It will be apparent that the grooved rolls permit the closing of the rolls and thus its operation is substantially as flexible as that with a conventional two-high rolling mill, except of course the width of the rolled slab now remains constant. By such configuration I obtain the marked reduction in edge cracking previously alluded to. The restraining elements prevent side spread and rolling is carried out under plane strain conditions. Thus the development of harmful secondary tensile stresses is entirely suppressed.

By employing edge restraint through elements that do not form part of the rolls my invention solves all of the earlier mentioned problems associated with the elimination of edge cracking. The material is laterally supported in the entire zone of deformation. Velocity differences between the rolled material and the restraining elements are reduced to a minimum and the material may be re-entered into the same pair of rolls for succession of passes with zero spread. The rolled product is readily removed from the roll gap without twisting or scraping.

A number of materials were rolled with edge restraint as herein taught to clearly point up the edge cracking prevention resulting from my process. For example:

Aluminum alloy slabs containing 8% magnesium were prepared and subjected to rolling both with and without edge restraint as herein taught. All slabs of this material rolled without such restraint invariably cracked at the edges whereas the restrained ones gave perfect parallel edges absolutely free of cracking.

Powder bodies of iron powders were made by ramming them into shape and then rolling at 2400° F. both with and without edge restraint as herein taught. The non-restrained bodies cracked severely; their density was approximately 70% of theoretical density of iron after 70% to 80% reduction in thickness. Similar powder bodies rolled with edge restraint as herein taught gave dense bodies free of edge cracks and with mechanical properties similar to those of typical hot rolled slabs. In this particular aspect of my invention an appropriate protective atmosphere should be employed.

Metal powder bodies were made by ramming them into a mild steel sheath. When rolling without edge restraint the sheath broke open and much of the powder escaped. By using the restraining bars the rolled body was free of edge cracking and yielded a much superior compacted product with a density approaching theoretical after only 70% reduction in thickness.

In the foregoing embodiment of my invention the process and apparatus is primarily suited for operation in

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reversing mills where a succession of passes may be taken on one and the same slab without need of separating the slab from the restraining elements. In another embodiment hereof as illustrated in FIG. 3 the restraining elements are in the form of endless belts 21. Here such belts fit into lateral grooves 22 on the rolls. While the thickness of such belts is of necessity limited by the requirement to maintain their flexibility adequate strength can be obtained for edge restraint purposes in view of the support that such belts receive from the portion of the rolls which form the outer wall of the grooves 22. The clearance between belts 21 and grooves 22 is greatly exaggerated in the schematic illustration of FIG. 3.

The present process and apparatus can also be employed for cladding. For this purpose a cladding material may be fed through the input side of the roll pair onto the base metal or other material being rolled with edge restraint.

The present process may also be employed in the rolling of materials other than metals. For example ceramics which are sheathed or canned in a metal may be rolled with edge restraint to prevent edge cracking of the composite structure.

It should also be evident to those skilled in this particular art that the present process may be employed in the rolling of complex shapes rather than mere plates or sheets as hereinabove described. As is more clearly described hereinafter with reference to FIG. 5 my process will likewise prevent edge cracking in such shapes which hitherto were subject to such detrimental phenomena.

In the compaction and rolling of loose particulate matter as herein taught, a variety of known means can be employed to bring such matter into position in the roll gap. I prefer, however, that a pair of converging belts be used to convey, for example, powders into the gap. This is illustrated schematically in FIG. 4. Here again there is an upper and lower roll 11 and 12 respectively and edge restraint is provided by belts or rings 23. To bring the powders in, endless belts 24 and 25 are mounted on rollers and positioned as shown. The belts 24 and 25 together with the restraining elements 23 define a feeding throat which tapers into the roll gap. By virtue of the movement of all four sides of the feeding throat, powder is drawn and thickness reductions far in excess of those normally obtained may be accomplished. Obviously this structure may be employed in either a vertical or horizontal plane or configuration.

As noted above, the present process and apparatus, with very slight modification, may be used for the continuous casting of metals and the like. In this embodiment the preferred apparatus is disclosed in FIG. 3 but for casting both the rolls (numbers 11 and 12 of FIGS. 1 and 2) are cooled and the two endless, flexible belts 21 and 22 are also cooled. As noted above as regards FIG. 3 the rolls are driven and the belts may be driven or dragged by the rolls. Such belts are fully supported in the grooves of the rolls. The two rolls and the two belts fully enclose and define a mold of rectangular cross section. All four walls of this mold move together with the solidifying ingot at a rate selected for the material being cast. Friction is completely eliminated and separation of the ingot from the mold is automatically accomplished. Pouring rates are so adjusted that the porosity is eliminated in the converging section of the mold.

A modified form of the present invention is shown in FIG. 5, wherein parts similar to those shown in FIGS. 1 and 2 are indicated with the same reference numeral and the subscript *a*. The apparatus includes a top roll 11_a and a bottom roll 12_a. The top roll has a central barrel portion 26 corresponding to the area between the grooves in FIG. 1 which is of a noncircular configuration. In the embodiment shown the central barrel portion is provided with four recesses equally spaced around the circumference. The resultant raised sections 29 and the recessed sections 28 correspond to the top surface of the

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shapes to be rolled. In like manner the bottom roll 12_a also has a central barrel portion 27 made up of similar recessed sections 30 and raised sections 31. In this embodiment each of the recessed sections 28 and 30 and each of the raised sections 29 and 31 is geometrically symmetrical. The top roll 11_a and the bottom roll 12_a are rotated in opposite directions to cause the opposing faces to move the workpiece 13_a in the same direction in conventional rolling fashion. The respective raised sections 29 and 31 oppose each other as do the recessed sections 28 and 30 during the rolling operation. This coordination is accomplished by conventional means such as gears. The workpiece 13_a which enters the rolls as a bar of uniform cross section is transformed by the central barrel portions of the rolls 11_a and 12_a into a periodic configuration of thick and thin sections in uniformly repeating patterns.

The lateral restraint is again accomplished by movable bars 16_a. The remainder of the apparatus is essentially the same as that shown in FIGS. 1 and 2. The flexible belts of FIG. 3 could again be substituted for the rigid bars shown in FIG. 5. The workpiece 13_a is transformed by rolling from its initial cross sectional shape into the desired configuration. The reduction is accomplished without edge cracking due to the presence of the restraining bars 16_a. Reductions in thickness up to 84% have been achieved without edge cracking or the formation of flash. The only limitation on use of the apparatus for periodic rolling is that the transitional surface of the rolls connecting the raised sections and the recessed sections should not be undercut. Undercutting of this transitional surface results in the pulling or tearing of the workpiece as the roller attempts to free itself.

While the modification shown in FIG. 5 lends itself readily to the one step rolling of any nonuniform shape the invention finds particular application in the field of rolling turbine blades.

Typical turbine blades formed by the process and apparatus of this invention are shown in FIGS. 6 and 7. FIG. 6 shows a continuous section of the workpiece after rolling and before cutting. The thick section defines root portions 32 of two blades disposed end to end. The thin section defines airfoil portions 33 of two blades disposed end to end. After cutting at the points indicated each turbine blade has the form shown in FIG. 7 or its mirror image. The airfoil portion 33 shown in FIG. 7 is laterally curved and tapered, however, it is not disposed at an angle to the root portion.

The airfoil cross section 33 shown in FIG. 7 is formed by one raised section 29 rolling in coordination with one raised section 31 in FIG. 5. For this particular application the raised section 29 of the upper roll 11_a is of a shape identical to the top boundary of airfoil 33. Mating raised section 31 is of a shape identical to the bottom boundary of airfoil 33. The shape of the airfoil 33 and its angle to the root section 32 is wholly a function of the shapes of the respective raised and recessed sections of the central barrel portions of the rolls. If no mirror image blades are desired, the rolls can be designed to make only duplicate blades connected root to foil to root. Application of the present invention to the rolling of turbine blades will be more clearly understood with reference to the following specific examples.

Turbine blades have been rolled with apparatus similar to that shown in FIG. 5. The width of the turbine blade and of the workpiece inserted in three quarters of an inch. This width is maintained by spacing the restraining bars at three quarters of an inch and having the width of the central barrel portion of the top and bottom rolls also of three quarters of an inch width. Each turbine blade is 2¼ inches in total length. The airfoil section is one and three quarters inches long and the root section ½ inch long. The starting material is fed into the roll at a thickness of three fourths of an inch. The material is passed through the rollers in a single pass which produces turbine blades

having an airfoil thickness of 0.125 inch and a root thickness of 0.525 inch. The raised portions of the rolls are correspondingly cut at a thirty degree angle to the roll axis resulting in an airfoil portion which is also at a thirty degree angle to the sides of the root portion. The materials employed for this turbine blade configuration were 7075 aluminum alloy rolled at 800° F. and Ti—6Al —4 v. alloy rolled at 1800° F.

A larger turbine blade has been made from 7075 aluminum alloy rolled at 800° F. The finished blade is one and fifteen-sixteenths inches wide and 3.1 inches long. The airfoil section is 2.6 inches long. The root thickness is .430 inch with the airfoil being again 0.125 inch. This airfoil is laterally curved and is rolled with no angle relative to the root section.

It will be evident to one skilled in the art that many other complex shapes can be rolled without departing from the scope of this invention. Turbine blades have been employed merely by way of example. The central barrel portions of the rolls may be designed to yield one or several repetitions per revolution. One roll may be cylindrical and one irregular in shape. The variations in geometry are almost unlimited.

The apparatus may be used for making preforms or for making end items. The tolerances of the roller parts depend on whether the product is to be subjected to one final forging step or used as rolled. In either case the process saves from 4 to 6 steps needed for current forming methods.

It will be understood that various modifications and variations may be affected without departing from the spirit or scope of the novel concepts of my invention.

I claim:

1. A method of rolling a series of periodic shapes from a workpiece of relatively constant cross section comprising the steps of:

feeding a workpiece between a pair of rolls each having a pair of opposing circumferential grooves, at least one of said rolls having a noncircular cross section, and

restraining the sides of said workpiece from lateral movement by means of a pair of relatively incompressible restraining bars received in said grooves and moving rectilinearly in the direction of the workpiece throughout the rolling zone to limit lateral deformation of said workpiece during the rolling operation whereby the tensile forces along the lateral edges are sufficiently reduced to prevent edge cracking.

2. Apparatus for rolling materials with complete lateral restraint comprising:

a pair of rolls having spaced parallel rotational axes, a pair of relatively incompressible elongate lateral restraining members arranged to define a four sided enclosure in the plane common to said axes, said members being movable in the direction of rolling to limit lateral deformation of the workpiece during the rolling operation whereby the tensile forces along

the lateral edges are sufficiently reduced to prevent edge cracking.

3. The apparatus defined in claim 2 further comprising two pair of opposing grooves in said rolls, said lateral restraining members being guided and supported in said grooves.

4. The apparatus defined in claim 2 wherein said lateral restraining members are rigid bars.

5. The apparatus defined in claim 2 wherein said lateral restraining members comprise endless incompressible belts of relatively flexible material which receive their support from the walls of said grooves.

6. The apparatus defined in claim 2 wherein at least one of said rolls is of a noncircular profile with respect to its rotational axis.

7. An apparatus for rolling materials comprising a pair of spaced rolls having parallel axes of rotation and defining a roll gap therebetween, each of said rolls including a pair of circumferential grooves in register with the corresponding grooves on the opposite roll, and

a pair of lateral restraining members extending in the direction of rolling and received in the respective opposing grooves on said rolls, said lateral restraining members being adapted for movement with the material to be rolled and further being relatively incompressible so that they cooperate with said rolls and said grooves to provide complete lateral restraint throughout the rolling pass whereby the tensile forces along said lateral edges are sufficiently reduced to prevent edge cracking.

8. A method as defined in claim 1 further comprising the step of cutting the rolled shapes from the workpiece.

9. A method of rolling materials between at least one pair of rolls comprising the steps of:

feeding a workpiece between a pair of rolls each having a pair of opposing circumferential grooves, and restraining the sides of said workpiece from lateral movement throughout the rolling zone by means of a pair of relatively incompressible restraining bars received in said grooves and moving rectilinearly in the direction of the workpiece whereby the tensile forces along the lateral edges are sufficiently reduced to prevent edge cracking.

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U.S. Cl. X.R.

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