Dec. 19, 1967 S. M. JENKS ET AL 3,358,358

METHOD OF REDUCING WIDTH OF METAL SLABS

Filed Dec. 31, 1964 3 Sheets-Sheet 1

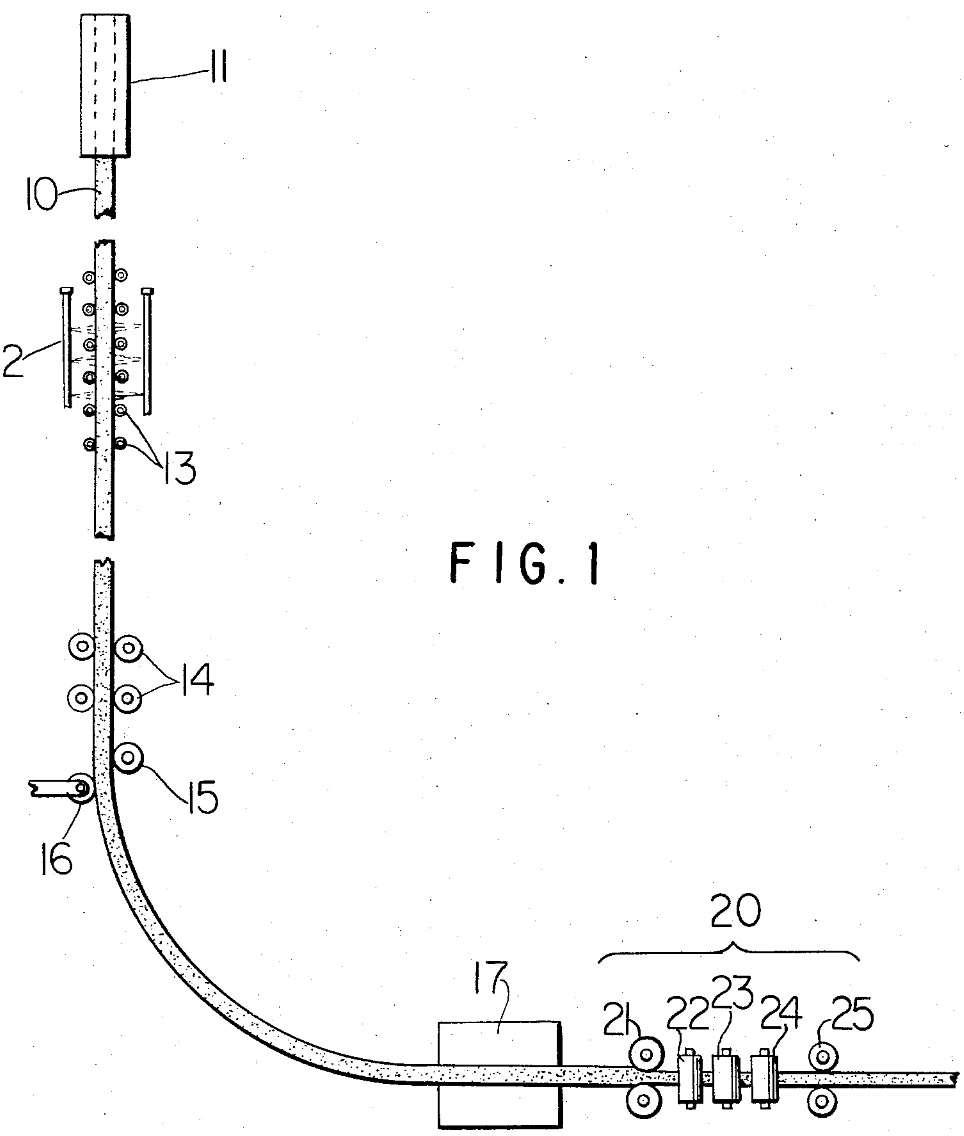

FIG. 1

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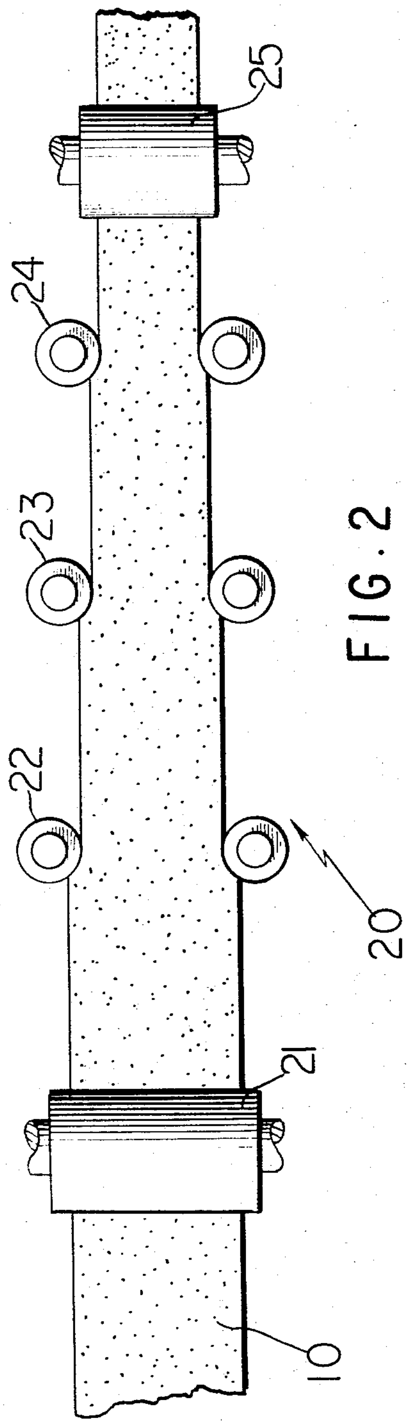

FIG. 2

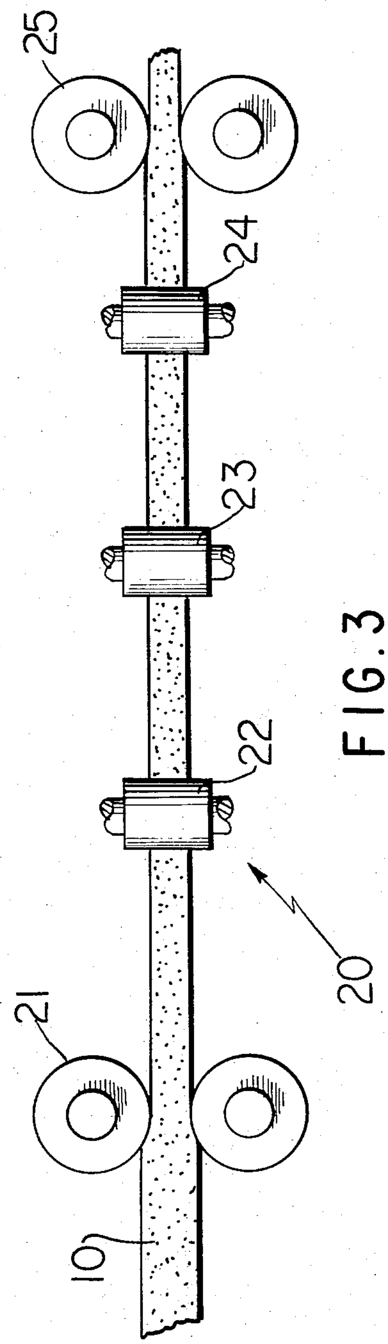

FIG. 3

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METHOD OF REDUCING WIDTH OF METAL SLABS

Filed Dec. 31, 1964 3 Sheets-Sheet 3

FIG. 4a

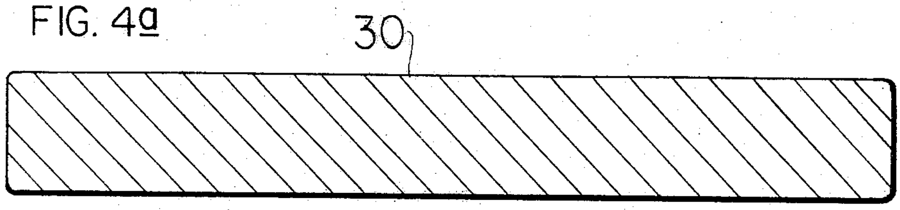


FIG. 4b

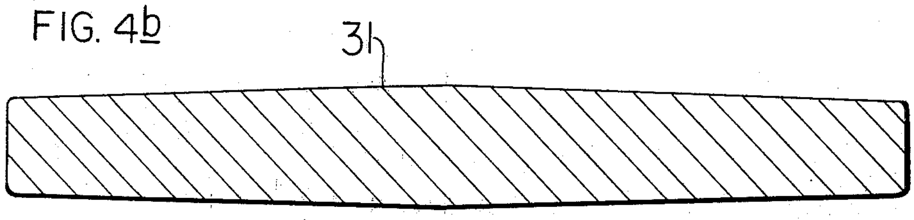


FIG. 4c

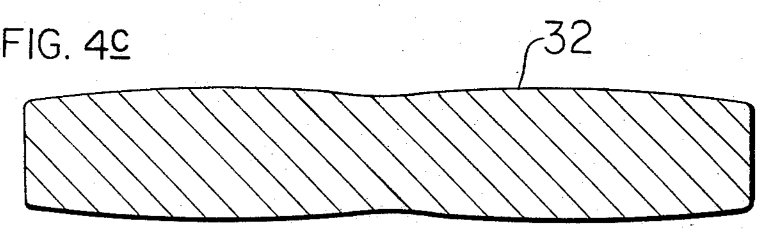


FIG. d

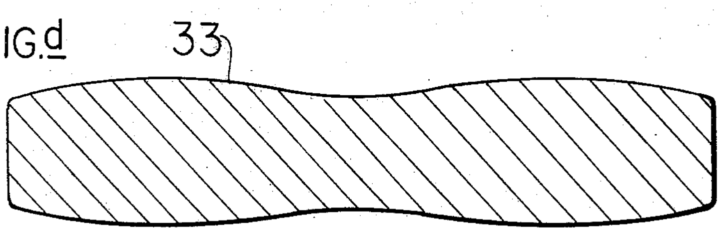


FIG. 4e

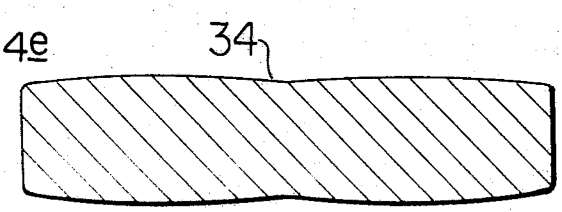
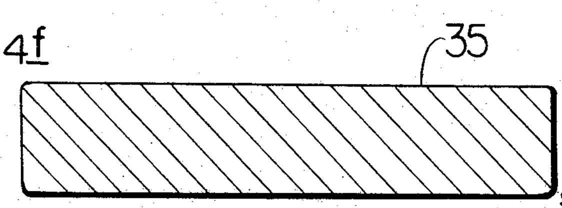


FIG. 4f



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United States Patent Office

3,358,358
Patented Dec. 19, 1967

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3,358,358
METHOD OF REDUCING WIDTH OF METAL SLABS

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Filed Dec. 31, 1964, Ser. No. 422,726
7 Claims. (Cl. 29—528)

ABSTRACT OF THE DISCLOSURE

A method for producing slabs of various widths from a continuously cast slab of the maximum width desired, by edge rolling the slab of maximum width while applying longitudinal tension thereto between spaced horizontal-roll stands, thereby reducing the tendency toward a "dog-bone" sectional shape as a result of the edge rolling.

This invention relates to processes for the continuous formation of semi-finished metal sections such as slab and, more especially, to processes for reducing such sections to desired width. A preferred practice of this invention relates to processes for reducing continuously formed steel castings to slabs of desired width.

The production of steel sheet and tin plate by continuous casting potentially offers greater efficiency than production according to conventional ingot casting. The advantages of continuous casting had not been fully realized prior to this invention, however, because it was thought that the only ways to obtain a coil of desired width were either to form a casting of predetermined width with allowance for changes in dimension during rolling and edge trimming, or to cut the casting into slabs and roll these slabs according to conventional rolling techniques. The former would require a multiplicity of molds, one for each slab width plus replacement molds for each slab width. A more serious drawback than the large inventory of molds is that it would be necessary to shut down the continuous-casting line and make a time consuming mold change every time it is desired to change from one slab width to another. Moreover, the required coil widths are not necessarily, in fact, not usually, the prefered widths from the standpoint of efficiency in the formation of the casting. Rolling the casting into sheet by conventional procedures would reduce to a considerable degree the advantages expected from continuous casting, and would be even less efficient than casting the steel to desired coil width.

The principal object of our invention is to make possible the production of continuously cast slabs in a multiplicity of desired widths from a single continuously formed casting which is at least as wide as the widest slab desired.

According to our invention, a metal section having a width at least as wide as the width of the widest slab desired is continuously formed, as for example by continuous casting, and this section is then reduced to desired width by edge rolling while maintaining the section under tension.

Our invention will now be described with respect to the accompanying drawing, in which:

2

FIG. 1 is a diagrammatic view of a continuous-casting apparatus suitable for carrying out our invention, showing all apparatus from the mold in which the casting is formed through the rolls in which edge rolling according to our invention is carried out;

FIG. 2 is a diagrammatic illustration of the edge rolling apparatus in plan view in which the process of our invention is carried out;

FIG. 3 is a diagrammatic side elevation of the apparatus in which the process of our invention is carried out; and

FIGS. *4a 4b, 4c, 4d, 4e* and *4f* are diagrammatic illustrations of the cross sectional shapes which a typical slab assumes during various stages of the rolling process of our invention.

Referring now to FIG. 1, a steel casting **10** is continuously formed in a conventional open-ended tubular vertical mold **11**, cooled by water sprays **12** and guided by guide rollers **13** as it descends below mold **11** under the control of pinch rolls **14**, bent by a bending apparatus which may include fulcrum roll **15** and pusher roll **16**, and reheated preparatory to edge rolling in a reheat furnace **17**. Finally, the reheated casting is rolled according to this invention into a slab having a width less than that of the casting. This is accomplished in an edge-rolling apparatus indicated generally at **20** and including a horizontal-roll stand **21**, a plurality of vertical-roll stands **22**, **23**, and **24**, and a second horizontal stand **25** which follows the vertical-roll stands. The casting is maintained under tension while it is rolled in apparatus **20**, so that substantial changes and distortions in the thickness direction are prevented.

Mold **11**, water sprays **12**, guide rolls **13**, pinch rolls **14**, fulcrum roll **15**, pusher roll **16**, and reheat furnace **17** are known elements in continuous-casting apparatus. Hence details of these elements and their operation do not form part of this invention.

The average temperature of the casting as it enters reheat furnace **17** is sufficiently high for hot rolling, due to the high temperature of the interior of the casting. "Average temperature" refers to the temperature of an equivalent casting having the same heat content per unit weight and a uniform temperature throughout. However, the surface of the casting, especially the corners, may be below hot-rolling temperature. Water sprays **12** may cool the casting surface to temperatures below hot-rolling temperature. Meanwhile the core of the casting gradually solidifies as heat is transferred to the surface. As the casting descends below sprays **12**, heat continues to be transferred from the core to the surface of the casting, causing some reheating of the surface, i.e. equalization of temperature. This reheating usually is not sufficient to equalize or bring the surface up to desired rolling temperatures; hence reheat furnace **17** is provided. Reheat furnace **17** may be omitted when both the average temperature and the surface temperature of the casting are sufficiently high for hot rolling.

While any hot-rolling temperature is suitable, it is preferable to use temperatures which are well above the recrystallization temperature. The temperature of the casting as it enters rolling apparatus **20** must be at least about 1900° F. for low-carbon grades containing approximately .04–.08% carbon. As the carbon content of the steel increases, the minimum permissible temperature of the slab entering apparatus **20** becomes lower, since recrystallization temperature drops with increasing carbon content in the low-carbon range. Although the average temperature of the casting entering rolling zone **20** may be as low as 1900° F., it is generally much more advantageous to introduce the casting into rolling zone **20** at a higher temperature, for example, about 2100° F. to 2200° F. The amount of work required for rolling is approximately doubled for every 300° F. drop in casting temperature. Hence work input is minimized by maintaining the casting at a high temperature.

Metal of any composition which can be continuously formed into semi-finished sections can be edge rolled according to this invention. The term "metal" herein includes both metallic elements and alloys. Copper, brass, aluminum, titanium, iron, and steel, for example, can all be edge rolled according to this invention. This invention is especially applicable to low-carbon steels, stainless steels, killed and semi-killed steels, and any other steels which may be continuously cast.

The casting **10** as it enters rolling apparatus **20** is preferably rectangular or substantially rectangular in cross-sectional shape. The sides of the casting need not be absolutely flat but may be slightly concave or convex, for example; castings having such sides may be readily rolled according to this invention and are herein deemed to be substantially rectangular in cross-sectional shape. Frequently the sides of the casting become slightly concave in cooling due to unequal cooling rates on different parts of the casting surface. Generally no major change in shape of the casting takes place from the time it is formed until it enters rolling apparatus **20**, although there is appreciable shrinkage in the casting as it cools.

Although castings of rectangular or substantially rectangular cross-sectional shape prior to rolling are preferred, it is understood that this invention is also applicable to metal sections of other cross-sectional shapes, such as oval, circular, or even irregular shapes. Specially shaped rolls in apparatus **20** may be required for the rolling of non-rectangular metal sections.

Castings having a width to thickness ratio in the range of 2:1 to 20:1 are readily rolled according to this invention to reduce their width; this can be accomplished without major changes in the thickness. Generally the process of this invention is not applied to castings in which the ratio of width to thickness is less than 2:1, such as square castings, for these may be advantageously rolled to smaller size by conventional techniques such as those employed in billet mills, for example. On the other hand, it is generally very difficult to reduce the width according to this invention in castings having an initial width to thickness ratio exceeding about 20:1. The application of vertical rolls to such wide and thin castings tend to cause buckling.

The minimum thickness of steel castings which may be rolled without difficulty according to the present invention is about 3 inches. Thinner castings tend to lose heat too rapidly so that they fall below hot-rolling temperature during the rolling process. Furthermore, such thin castings generally do not have sufficient structural strength to withstand the edge-roll pressures which are necessary to achieve the desired width reduction. The minimum thickness which can be conveniently rolled varies somewhat from metal to metal and can be determined by those skilled in the art. The maximum thickness of castings which may be rolled according to the present invention is limited only by the maximum thickness of castings which can be formed by continuous casting. As is well known, the low heat-transfer rate of steel and the resulting cooling problems impose an upper limit on casting thickness beyond which continuous casting is not practicable.

For convenience it is preferred to roll the casting according to this invention as it is traveling horizontally. Hence edge rolls **22, 23,** and **24** wil be referred to herein as vertical rolls. Face rolls **21** and **25** will be referred to as horizontal rolls. The casting may be deflected from its initial vertical direction to a horizontal direction by any desired means, such as the fulcrum roll **15** and pusher roll **16** herein illustrated. Other bending means may be used if desired.

The casting passes continuously from mold **11** to edge-rolling apparatus **20**. Hence, the casting speed determines the speed at which rolling in apparatus **20** takes place. The maximum speed of rolling in apparatus **20** is limited by the speed at which a casting can be conveniently formed. The exit speed of the casting as it leaves the last horizontal roll stand **25** in edge-rolling apparatus **20** will seldom exceed about 50 feet per minute. Generally the exit speed will be much less than this, for it is seldom feasible to form a casting at a rate sufficiently fast to result in a slab exit speed of 50 feet per minute.

The rolling apparatus **20** as herein illustrated includes a horizontal-roll stand **21** at the entrance end, a second horizontal-roll stand **25** at the exit end, and a plurality of vertical-roll stands **22, 23,** and **24** therebetween. Three vertical-roll stands **22, 23,** and **24** are shown herein merely for purposes of illustration. As few as two vertical-roll stands may be provided between the horizontal-roll stands **21** and **25**, or more than three vertical-roll stands can be provided if desired.

In cases where substantial width reduction, e.g., about 60% or more of the original width, is desired, it may be advantageous to use three or more horizontal-roll stands with two vertical-roll stands between each pair of successive horizontal-roll stands. The total length of the rolling apparatus of this invention is limited by the cooling of the slab which occurs as it passes through the apparatus, since the slab must remain at hot-rolling temperature throughout the process.

Both horizontal-roll stands **21** and **25** are power driven, and preferably all vertical-roll stands **22, 23,** and **24** are also power driven. Variable-voltage direct current motors are particularly advantageous.

The amount of reduction in cross-sectional area achieved in rolling apparatus **20** is approximately directly proportional to the power input to the apparatus at a given temperature. As already noted, power requirements to achieve any given size reduction approximately double with every 300° F. temperature loss. Although the power input into the apparatus **20** as a whole must be equal to that required for reducing slab cross-sectional area, the work input into any individual stand may be greater or less than that consumed by the sectional-area reduction made in that stand.

It is important to maintain the casting under tension as it is being rolled, in order to obtain a casting of substantially rectangular cross section as it leaves rolling apparatus **20**. By so doing, substantial reductions in width, as much as 50% or even more, can be achieved while obtaining a slab of rectangular cross section. Failure to maintain the casting under tension results in a slab of irregular shape, often approximately that of a dumbbell or a dog bone, as the casting enters the exit horizontal rolls **25**. Tension on the casting can be maintained very simply by applying the greater part of the power input to the exit horizontal rolls **25** and the last vertical-roll stand **24**, and operating the first horizontal-roll stand **21** and the first vertical-roll stand **22** at relatively low power inputs. When this is done, the power consumed in reducing the cross-sectional area of the casting in the initial horizontal-roll stand **21** and the first vertical-roll stand **22** is greater than the power inputs to these stands. Conversely, the power inputs to the final vertical-roll stand **24** and the exit horizontal-roll stand **25** are greater than the amounts of power consumed in reducing the cross sectional area in those stands. In effect, roll stands **24** and **25** pull the casting through the entire rolling apparatus **20**, and thereby maintain tension on the casting.

The rolls in the initial horizontal-roll stand **21** are preferably concave in order to reduce the casting thickness at the edges without appreciable reduction at the center. This compensates for the thickening near the edges which occurs in subsequent edge rolling in vertical-roll stands **22**, **23**, and **24**. Exit horizontal rolls **25** are substantially cylindrical in order to obtain a rectangular slab.

The edge rolls **22**, **23**, and **24** have collars at the bottom to prevent the slab from dropping. To prevent the slab from climbing, the edge rolls may also have collars at the top, or alternatively may be slightly frusto-conical in shape, having sides tapering downwardly and inwardly by a small angle, say about 3.5° to 4°, from the vertical. All rolls preferably have roughened surfaces, such as knurled surfaces, in order to increase the frictional engagement between the rolls and the casting.

The shapes of a casting at different stages as it is being rolled under tension in rolling apparatus **20** are indicated diagrammatically in FIGS. 4*a* thru 4*e* of the drawing. These figures indicate the successive cross-sectional shapes which a typical casting assumes as it is being rolled. The casting has a rectangular shape **30** as it enters rolling section **20**. The concave horizontal rolls **21** tend to cause some bulging of the casting so that the faces have a slightly convex cross-sectional shape **31** (FIG. 4*b*) as it leaves rolls **21**. Some reduction in thickness takes place as a result of rolling by horizontal rolls **21**; it is generally desired to keep this amount as small as possible consistent with obtaining a finished slab of substantially rectangular cross-sectional shape.

Rolling in first vertical stand **22** causes considerable reduction in the width of the slab and simultaneously causes the slab to become slightly thicker near its edges without any increase in thickness along the longitudinal center lines on either face. The shape **32** (FIG. 4*c*) of the casting at this point is somewhat similar to that of a dog bone. Rolling of the edges accounts for the flow of metal which causes the thickening near the edges. Further rolling in the succeeding vertical-roll stands **23** and **24** causes further appreciable reduction in width as shown by cross-sectional shapes **33** and **34** of FIGS. 4*d* and 4*e*, respectively. The slab still retains generally the cross-sectional shape of a dog bone or a dumbbell at this point. Finally, rolling in the second pair of horizontal rolls **25** causes the faces of the casting to be flattened so that once again the rolled slab has a substantially rectangular cross shape **35** (FIG. 4*e*). The edges of the casting as it leaves horizontal rolls **25** may be slightly irregular or undulated, often being slightly convex near the corners and slightly concave in the vicinity of the longitudinal center lines of each edge.

Failure to maintain the casting under tension as it is being rolled will result in a casting having the shape of a dumbbell or a dog bone as it emerges from horizontal rolls **25** at the exit end of rolling apparatus **20**.

While this invention has been described with particular reference to rolling of steel slabs of substantially rectangular cross-sectional shape, this is by way of illustration of a preferred embodiment. Various modifications may be made by those skilled in the art as already indicated.

This invention will now be described with reference to specific examples. It will be understood that these examples are provided only for purposes of illustration and that various modifications may be made within the scope of this invention.

Example 1

A continuously formed steel casting was continuously advanced through the edge-rolling apparatus **20**. The average temperature of the slab as it entered was approximately 2200° F., and the surface temperature of the casting ranged from about 1900° F. to about 2100° F.

Table I below shows the dimensions, cross-sectional area, and speed of the slab initially (i.e., as it enters apparatus **20**) and after passage through each of the roll stands **21**, **22**, **23**, **24**, and **25**. This table also shows the roll diameter, spacing between successive rolls, and roll speed in each stand. The voltage, current flow, and power input (in both kilowatts and horsepower) for each roll stand are also given.

TABLE I

	Initial	Stand No.				
		21	22	23	24	25
Slab Width (in.)	27.0	28.12	22.25	21.75	14.50	14.75
Slab Thickness (in.)	7.25	6.35	7.75	7.75	8.0	6.38
Slab Area (sq. in.)	196	179	172	169	116	94
Slab Speed (in./min.)	37.5	41.0	42.5	43.5	63.2	78.0
Roll Diameter (in.)	--------	42	21	21	31	42
Roll Speed (r.p.m.)	--------	.31	.64	.66	.65	.59
Distance from Preceding Roll Stand (in.)	--------	0	59.3	23.5	28.7	62.5
Distance from First Horizontal Roll Stand (in.)	--------	0	59.3	82.8	111.5	174.0
Elapsed Time (min.)	--------	--------	1.44	.55	.66	.99
Elapsed Time, Cumulative (min.)	--------	--------	1.44	1.99	2.65	3.64
Motor Amps	--------	200	480	0	790	400
Motor Volts	--------	110	75	0	70	220
Motor kw	--------	22.0	36.0	0	55.3	88.0
Motor H.P	--------	29.6	48.5	0	74.4	118.4

Example 2

The apparatus used in this example consisted of horizontal rolls **21**, two vertical-roll stands **22** and **24**, and exit horizontal rolls **25**. Roll stand **23** was omitted. Each of the roll stands **21**, **22**, **24**, and **25** was driven by a direct-current motor.

A continuously formed steel casting was continuously advanced through the edge-rolling apparatus **20** modified by the omission of vertical-roll stand **23**. The average temperature of the slab as it entered was approximately 2200° F., and the surface temperature of the casting ranged from about 1900° F. to about 2100° F.

Table II below shows the dimensions, cross-sectional area, and speed of the slab initially (i.e., as it enters apparatus **20**) and after passage through each one of the roll stands **21**, **22**, **24**, and **25**. This table also shows the roll diameter, spacing between successive rolls, and roll speed in each stand. The voltage, current flow, and power input (in both kilowatts and horsepower) for each roll stand are also given.

TABLE II

	Initial	Stand No.			
		21	22	24	25
Slab Width (in.)	27.0	28.12	22.00	13.50	13.75
Slab Thickness (in.)	7.25	6.38	7.75	8.00	6.75
Slab Area (sq. in.)	196	179	170	108	93
Slab Speed (in./min.)	51.5	56.4	59.4	93.4	108.5
Roll Diameter (in.)	----------	42	21	31	42
Roll Speed (r.p.m.)	----------	.43	.90	.96	.82
Distance from Preceding Roll Stand (in.)	----------	0	59.3	52.2	62.5
Distance from First Horizontal Roll Stand (in.)	----------	0	59.3	111.5	174.0
Elapsed Time (min.)	----------	0	1.05	.88	.67
Elapsed Time, Cumulative (min.)	----------	0	1.05	1.93	2.60
Motor Amps	----------	75	380	580	240
Motor Volts	----------	140	115	115	300
Motor kw	----------	10.5	43.7	66.7	72.0
Motor HP	----------	14.1	58.6	89.4	96.5

Temperature measurements in Examples **1** and **2** indicate an average surface-temperature loss of about 300° F. as the slab progressed through the rolling stand **20**.

It will be noted in Tables I and II that most of the power input is to the final vertical-roll stand **24** and the exit horizontal-roll stand **25**. Although the amount of power required to achieve a given number of square inches reduction in cross-sectional area is greater in these roll stands than in roll stands **21** and **22** because of the drop in temperature of the casting, nevertheless it is evident that the amount of power input to roll stands **24** and **25** is greater than the power required for size reduction, and conversely, the power input into roll stands **21** and **22** is insufficient to achieve the size reduction which is actually achieved in each of these stands. Hence, the power input into roll stands **24** and **25** pulled the casting through roll stands **21**, **22**, and **23**. This pulling achieved the tension necessary to result in a slab of substantially rectangular cross-sectional area at the exit end of the rolling apparatus **20**. Accurate computation of the amount of tension is not possible because of the complex relationship between power requirement and rolling temperature and the absence of precise temperature data.

The amount of edge reduction may be less than that obtained in the above examples. It may also be slightly greater. The amount of edge reduction is determined by setting the rolls in each roll stand to the desired exit width or thickness of the casting as it emerges from that roll stand. Control of the power input to each roll stand determines the amount of tension on the casting. Of course, the total power input to the several roll stands must be equal to that necessary to obtain the desired size reduction.

It will be seen that our invention provides an efficient process for reducing continuously formed castings from a single width, approximately that of the mold, to a desired lesser slab width.

What is claimed is:

1. A process for making a metal slap comprising continuously casting metal to produce a casting of essentially rectangular cross section having a width greater than that of the slab desired, passing the casting through edge rolls to reduce its width while said casting retains sufficient heat for hot rolling, said reduction in width normally causing the metal in said casting to be laterally displaced to form a cross section of a dog-bone appearance to such degree that the faces of the casting cannot subsequently be flattened by rolling, and applying tension to said casting during edge rolling to materially reduce such lateral displacement.

2. A process according to claim **1** wherein said tension is applied by engaging the faces of the casting width rolls before and after engagement of the casting by edge rolls.

3. A process according to claim **1**, wherein the surface of said casting is heated prior to edge rolling.

4. A process according to claim **1** wherein said metal is steel.

5. A process according to claim **1** wherein said casting has an essentially rectangular cross section before and after edge rolling.

6. A process according to claim **2** wherein the rolls engaging the faces of the casting before edge rolling are shaped to impart transverse convexity to the slab section.

7. In a method of making slabs of various widths, the steps including continuously casting a slab of the maximum desired width and indefinite length thru a vertical open-ended mold, cooling said slab as it emerges from said mold but not below an average temperature less than hot-rolling temperatures, bending the slab to a horizontal path, equalizing substantially the temperature of the slab throughout its cross-section, edge rolling the slab to reduce its width and applying longitudinal tension to the slab on both sides of the zone of edge rolling.

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P. M. COHEN, *Assistant Examiner.*

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,358,358 December 19, 1967

Stephan M. Jenks et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, line 59, for "slap" read -- slab --; column 8, line 27, for "width" read -- with --.

Signed and sealed this 18th day of March 1969.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents