

[54] **METHOD OF REPETITIVELY IMPACTING SMALL PIECES OF METAL IN ORDER TO PRODUCE A DENSIFIED CONTINUOUS BODY**

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[52] U.S. Cl. .... 29/403, 29/420.5, 29/498.5,  
100/38, 425/421

[51] Int. Cl. .... **B22f 3/24**, B23q 17/00

[58] Field of Search ..... 29/420.5, 403, 498.5;  
100/35, 38, 232, DIG. 1; 425/421

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**FOREIGN PATENTS OR APPLICATIONS**

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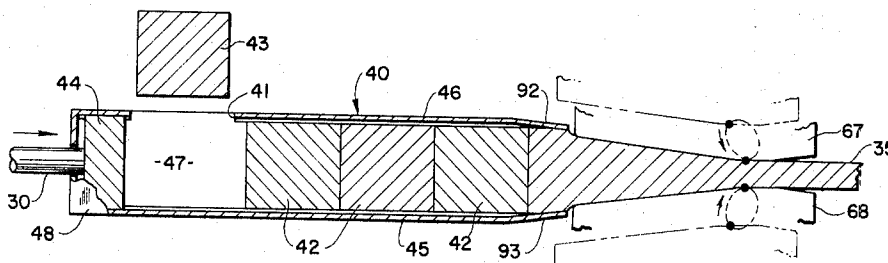
[57] **ABSTRACT**

A method and apparatus for forming metal products from scrap or other small pieces. Pieces of scrap metal are bonded together by baling into bales of from 20 percent to 50 percent metal by volume. The bales are then heated from 1,200°F. to 2,350°F. and fed through a feed magazine into a harmonic impacting press.

Deformation of bales prior to reaching the impacting station in the harmonic press is controlled by control of the press and by peripheral confinement of the bales prior to being fed into the impacting station in the press.

There is also a disclosure of a means to fuse bales together through use of a thermal powder.

**27 Claims, 13 Drawing Figures**



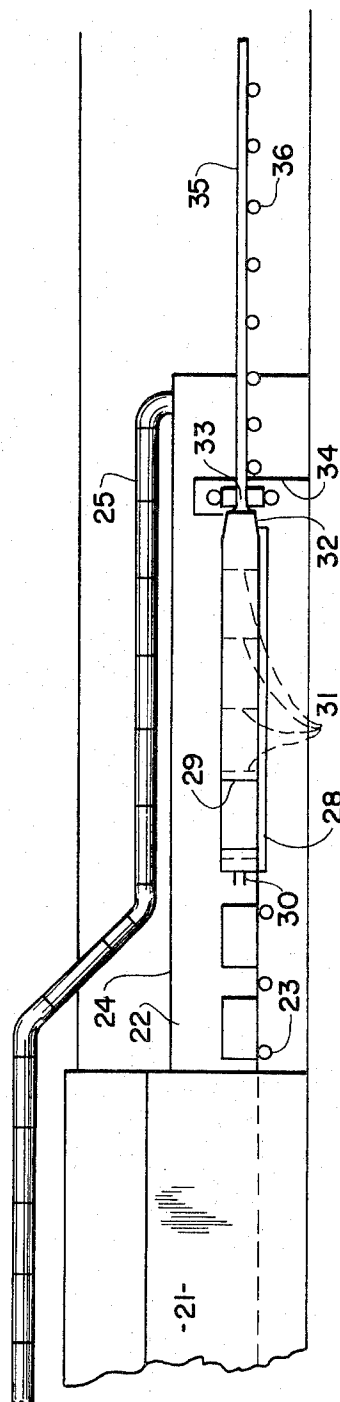
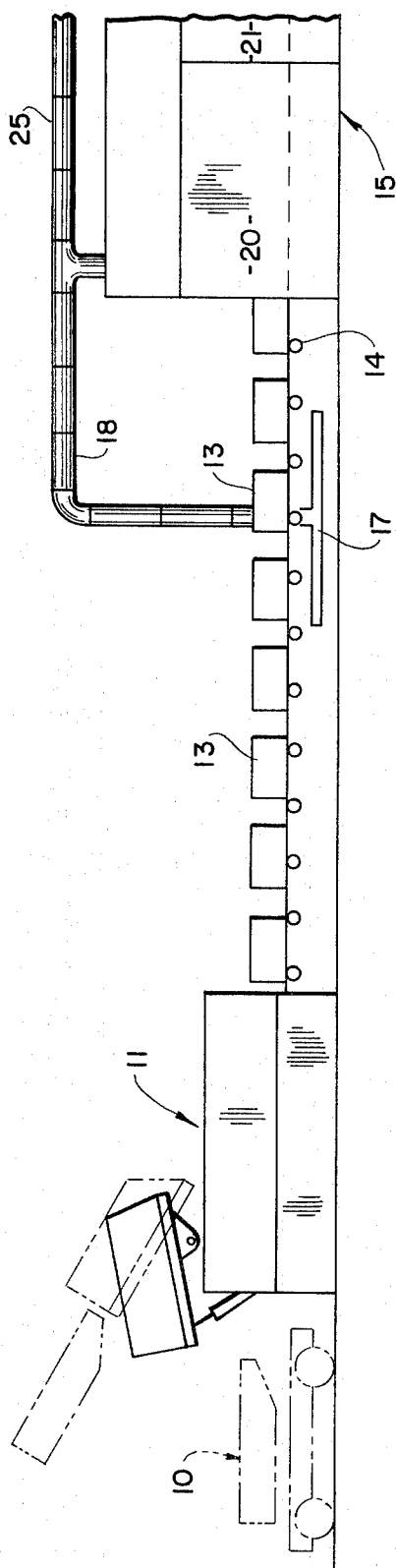


*Fig. 1*

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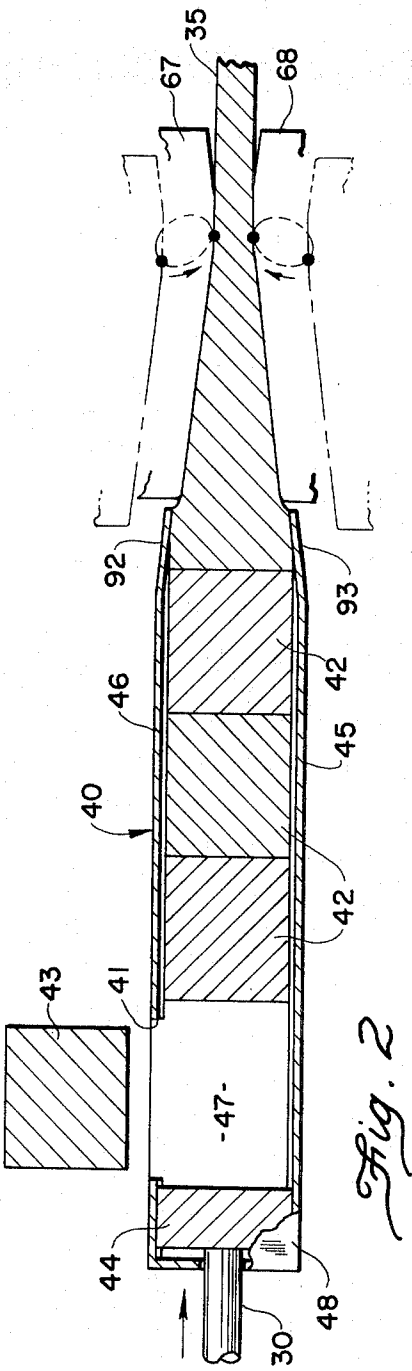


*Fig. 2*

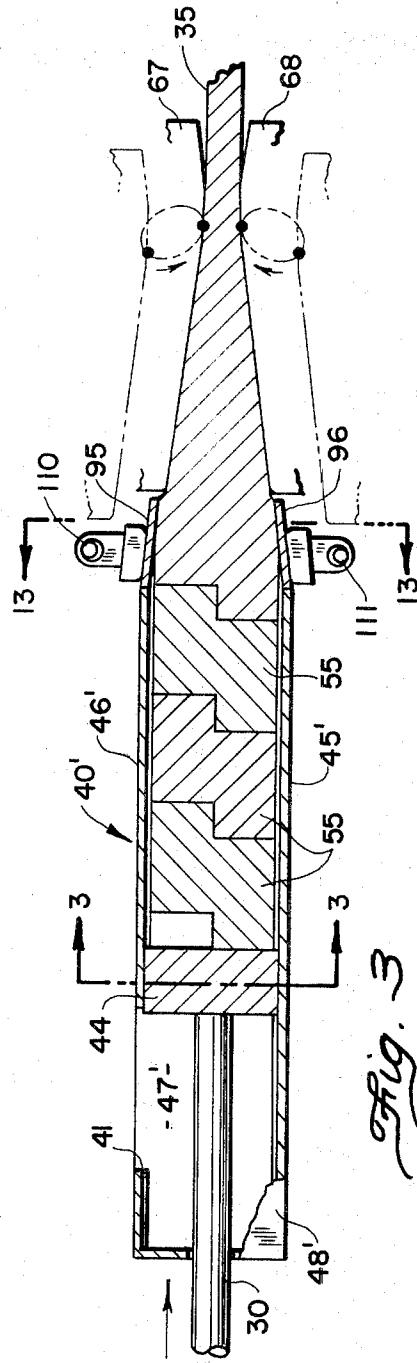


*Fig. 3*

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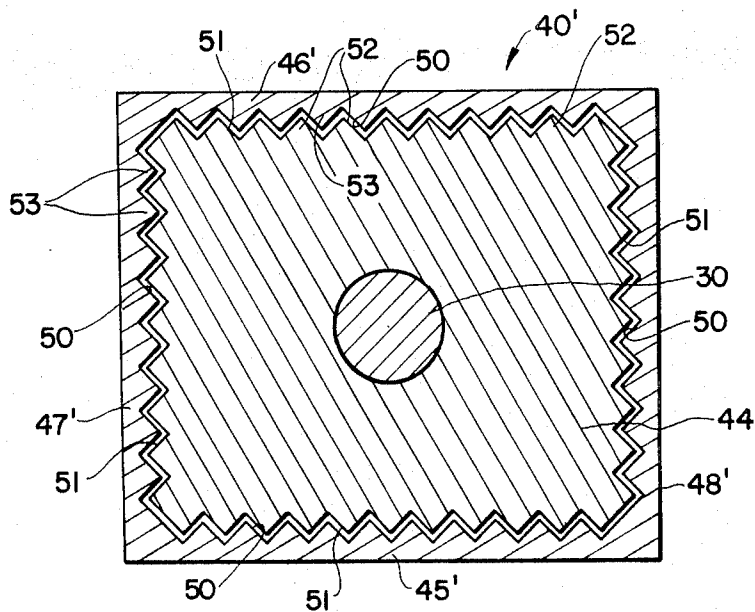


*Fig. 4*

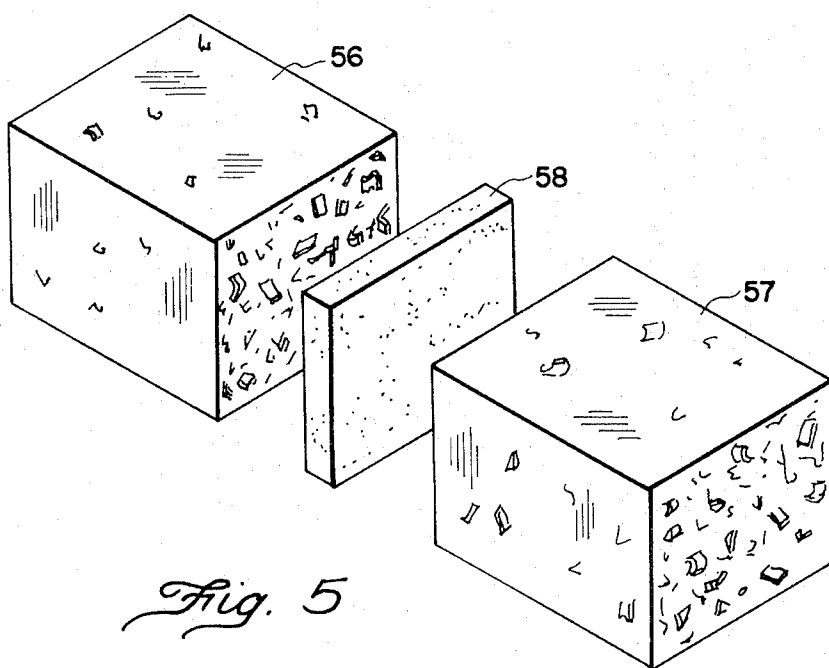


*Fig. 5*

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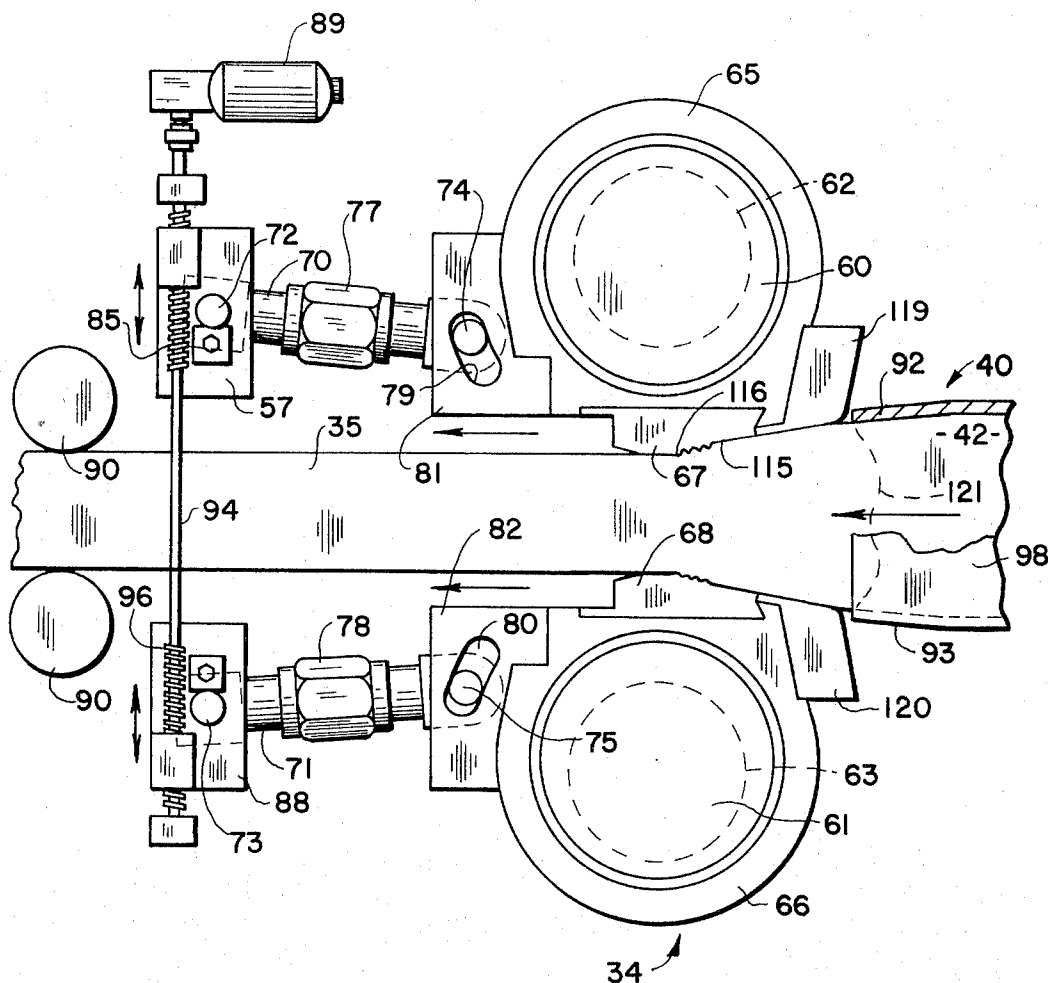


Fig. 6

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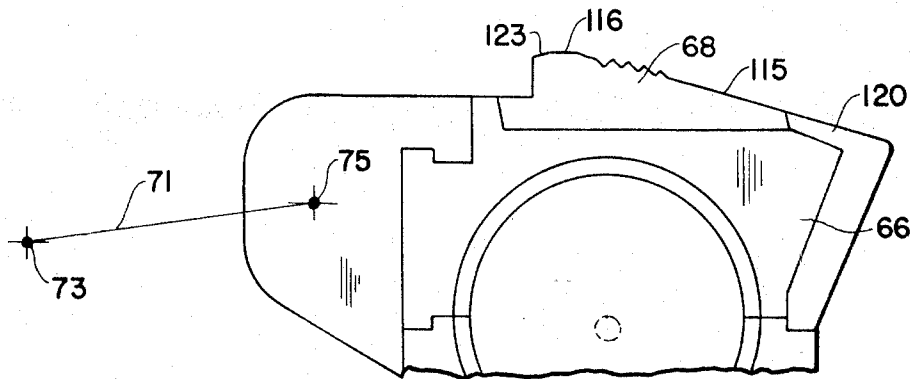


*Fig. 10*

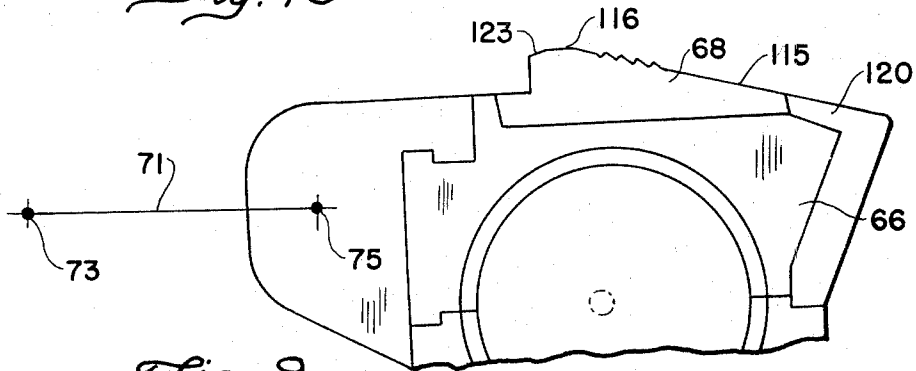


*Fig. 9*

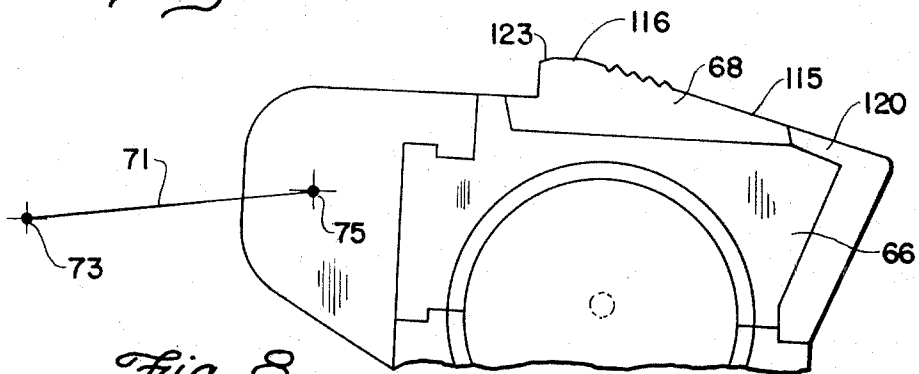


*Fig. 8*

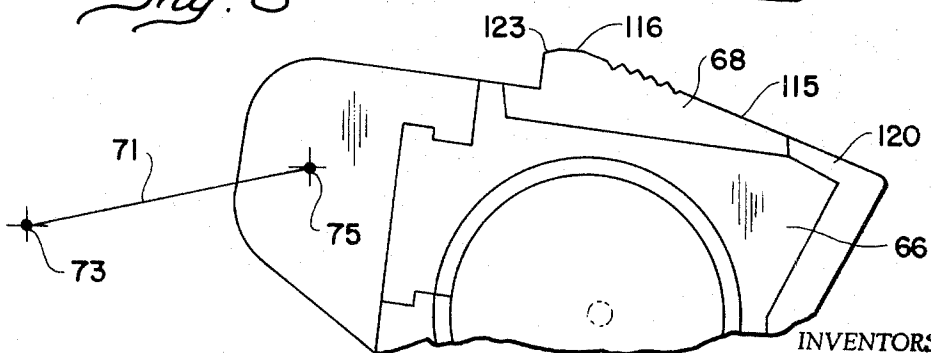


*Fig. 7*

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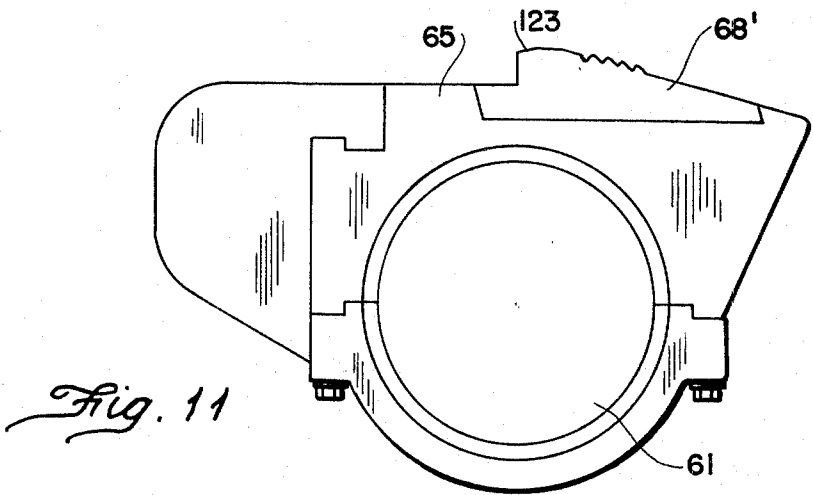


*Fig. 11*

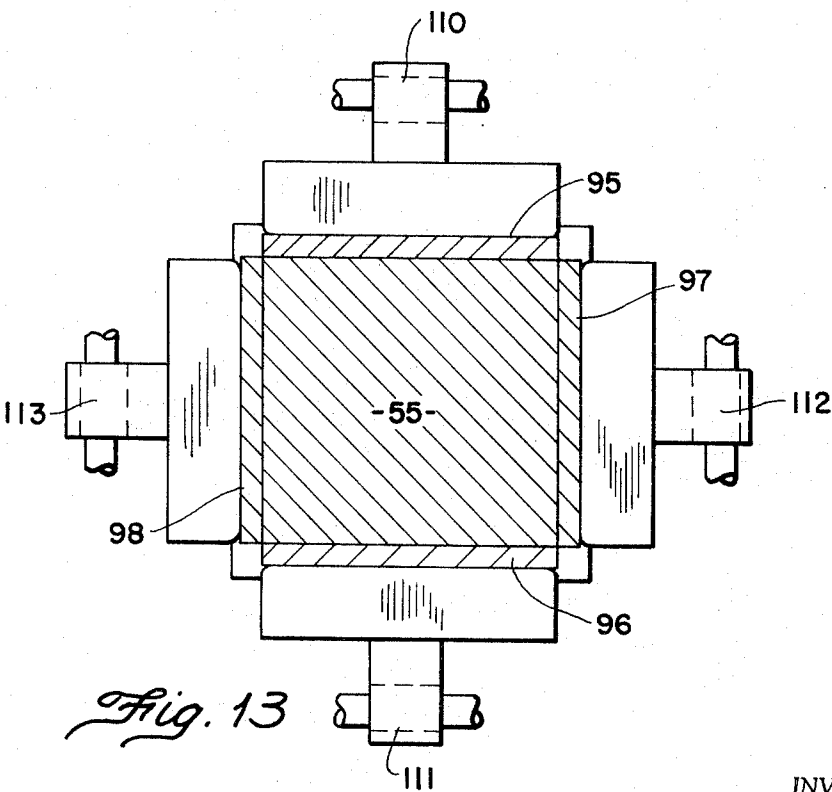


*Fig. 13*

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TEMPERATURE & RATE OF STRAIN EFFECT  
ON STEEL COMPRESSION STRESS

| TEMP.<br>°F | RATE OF<br>STRAIN<br>SEC. <sup>-1</sup> | AVERAGE STRESS (10 <sup>3</sup> LB/IN <sup>2</sup> ) TO COMPRESS |       |       |       |       |
|-------------|-----------------------------------------|------------------------------------------------------------------|-------|-------|-------|-------|
|             |                                         | 10%                                                              | 20%   | 30%   | 40%   | 50%   |
| 65          | SLOW                                    | 78                                                               | 93    | 99    | 103   | 106   |
| 1700        | 4.00                                    | 18.5                                                             | 22.25 | 23.25 | 23.6  | 23.75 |
|             | 8.00                                    | 19.1                                                             | 23.0  | 25.1  | 26.5  | 26.25 |
|             | 12.00                                   | 20.09                                                            | 23.8  | 25.7  | 26.85 | 26.9  |
|             | 24.00                                   | 21.65                                                            | 25.4  | 27.7  | 28.75 | 29.6  |
| 1850        | 4.00                                    | 14.35                                                            | 18.05 | 19.8  | 20.55 | 20.0  |
|             | 8.00                                    | 16.1                                                             | 19.0  | 21.0  | 22.1  | 22.1  |
|             | 12.00                                   | 16.8                                                             | 19.6  | 21.3  | 22.65 | 22.7  |
|             | 24.00                                   | 18.7                                                             | 21.75 | 23.15 | 24.65 | 24.6  |
| 1950        | 4.00                                    | 12.65                                                            | 15.0  | 16.3  | 16.8  | 16.0  |
|             | 8.00                                    | 13.75                                                            | 16.1  | 18.1  | 18.75 | 18.65 |
|             | 12.00                                   | 14.4                                                             | 16.8  | 18.45 | 19.4  | 19.9  |
|             | 24.00                                   | 15.45                                                            | 18.5  | 20.40 | 21.85 | 22.25 |
| 2075        | 4.00                                    | 10.9                                                             | 12.8  | 13.65 | 13.65 | 12.9  |
|             | 8.00                                    | 11.75                                                            | 13.65 | 14.9  | 15.4  | 14.95 |
|             | 12.00                                   | 12.35                                                            | 14.3  | 15.65 | 16.5  | 16.6  |
|             | 24.00                                   | 13.65                                                            | 16.0  | 17.5  | 18.5  | 18.75 |
| 2200        | 4.00                                    | 8.85                                                             | 10.5  | 10.8  | 10.8  | 9.9   |
|             | 8.00                                    | 9.6                                                              | 11.0  | 11.75 | 11.9  | 11.3  |
|             | 12.00                                   | 10.05                                                            | 11.4  | 12.35 | 12.5  | 12.25 |
|             | 24.00                                   | 11.00                                                            | 12.7  | 13.75 | 14.4  | 14.2  |

*Fig. 12*

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# METHOD OF REPETITIVELY IMPACTING SMALL PIECES OF METAL IN ORDER TO PRODUCE A DENSIFIED CONTINUOUS BODY

## CROSS REFERENCES TO RELATED APPLICATIONS

1. U.S. application for Pat. Ser. No. 121,861 filed Mar. 8, 1971 by Mark E. Whalen et al. entitled "Apparatus and Solid State Method for Converting Small Pieces of Metal to a Workpiece."

2. U.S. application for Pat. Ser. No. 122,110 filed Mar. 8, 1971 by Mark E. Whalen et al. entitled "Novel Apparatus and Solid State Method for Converting Small Pieces of Metal to a Workpiece."

3. U.S. application for Pat. Ser. No. 164,789 filed July 21, 1971 by Mark E. Whalen et al. entitled "Apparatus and Solid State Method for Converting Small Pieces of Steel to a Workpiece."

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention.

This invention relates to a novel and improved method of converting scrap metal pieces to a body of solid metal useful in manufacturing operations and, additionally, to an improved apparatus for carrying out the conversion.

### 2. Description of the Prior Art.

In conventional commercial processes for conversion of the scrap steel to commercial steel, the scrap metal is melted and then processed with conventional steel-making techniques. Other than the melting step, the scrap conversion does not involve any process which is uniquely demanded by the presence of scrap.

The referenced prior applications disclose a method and apparatus for converting steel scrap to useful commercial products such as coils of steel strip. With the process of the invention, relatively large slabs are made, but, as in conventional manufacture of strip steel from billets, the finished strip has spaced seams where the slabs are joined together.

According to the teachings of the referenced prior applications, the scrap is baled. When the bales are small they are joined together to form "jumbo bales" and then further processed. The further processing includes heating the bales to from 1,200°F. to 2,350°F. and then forging in a harmonic press to produce a unitary, cohesive, and solid one-piece slab.

While the referenced prior applications suggest formation of slabs with impaction of the bales while hot with a single pass through a harmonic press, the referenced applications also teach the use of a second press to cold compress the bales prior to heating. Alternatively, the prior applications teach multiple stages of hot compression, either by multiple passes through a single hot harmonic press, or the utilization of a plurality of hot presses.

## SUMMARY OF THE INVENTION

It has now been discovered that by appropriate control of forces transmitted into portions of the bale which have not yet entered the compaction station, and by appropriate control of the forging platens, a high-quality steel slab can be manufactured from a hot, relatively porous, bale in a single pass through a compaction or forging station in the harmonic press under a greatly increased range of conditions. In addition, in

accordance with this invention, it is now possible to manufacture a continuous steel slab so that a finished coil of steel strip can be free of any seams where strips from different slabs have been joined together; or, as is the case with some conventional steel-making techniques, where strips from billets have been joined together.

In operation of a harmonic press which is forging a bale into a steel slab, some of the impacting forces are transmitted longitudinally of the bale in directions generally opposed to the path of bale feed travel. If properly constrained and controlled, these forces precompress the portions of the bale immediately upstream along the feed path from the compression station to reduce the compaction subsequently necessary in the forging station. Moreover, with proper constraint and control a "pool" of precompressed bale pieces is developed. The pool is developed as feeding commences and after a brief period of time the pool reaches a relatively stable size. Once the pool has reached a stable size, it provides a quantity of relatively dense scrap material which resists the longitudinal dissipation of the compaction forces and thus assists in developing a highly efficient application of compaction forces in the forging press. If the impacting forces are not constrained and controlled, they cause the bale to bulge and these forces are uselessly dissipated.

The force control and confinement is accomplished by:

1. perimetally constraining the portions of the bale in the feed path adjacent the compression station;
2. by controlling the rate of feed of the workpiece, which control is also a function of the adjustment of the path of travel of the press anvils; and
3. further control of the path of travel of the anvil to achieve what is here referred to as "rate of strain". Rate of strain is analogous to, but different from, conventional "strain rate."

In the preferred embodiment, bales while hot are fed to a feed magazine. The feed magazine delineates an elongated bale feed path along which a plurality of bales are positioned in juxtaposed relationship.

The magazine is equipped with a reciprocal ram which is hydraulically or screw driven to force bales in the magazine into engagement with one another and thence along the feed path into the compression station. The ram is retractable and once retracted further bales may be fed through a suitable feed opening into the magazine.

The magazine is constructed so that rupture and tension of the bales due to the forces applied by the ram are prevented. In addition, portions of the magazine adjacent the outlet end and near the press compaction station are tapered to provide a funneling portion which precompresses the bale somewhat as it is fed to the compaction station. This precompression by funneling, coupled with the forces transmitted along the workpiece path from the forging station, produces the pool referred to above. Thus, there is a precompression zone where the pool of relatively dense material is developed.

The magazine walls in the funnel portion are preferably tapered at 5° to 15° with the path of bale travel. This taper contributes to the development of the pool of precompressed material.

To facilitate the incremental movement of the bales during a feed portion of an impacting cycle of the forging press, these tapered walls of the funnel portion can be made to reciprocate in synchronism with the anvils of the forging press during the feed portion of the cycle. Thus, the funnel portion is out of engagement with the bale during the feed portion of a cycle.

To assure that bales do not separate one from the other as one is fed through the compaction station, either or both of two procedures are followed. The first procedure is to maintain pressure on bales in the feed magazine with a ram at times when the lead edge of the bale is approaching and then being fed into the compaction station. Thus, loading of additional bales is accomplished in coordination after the commencement of self-feed of a bale through the forging press. The second technique is to weld bales together while in the magazine.

This welding of the bales while in the magazine is accomplished by placing a cake or package between the bales which are to be welded. The cake is composed of a mixture of steel powder and thermite. The thermite is a mixture of finely granulated aluminum with an oxide of iron or other metal interspersed through it. In the preferred arrangement, the ignition of the thermite is achieved by simply compressing the bales in the magazine, which compression, coupled with the heat of the bales, is sufficient to ignite the thermite and effect welding of scrap pieces in one bale to the scrap pieces in the adjacent bale.

The inner walls of the magazine are serrated and the perimeter of the ram has complementary serrations. If pieces of scrap tend to project from the bale, the crests of the magazine serrations will engage the pieces of scrap and maintain the scrap in spaced relationship with the base of the magazine serrations. As the ram advances, projections of its serrations will then extend laterally outwardly beyond any scrap and tend to roll any projecting scrap inwardly. In the absence of the serrations, there would be a tendency for such projecting pieces of scrap to become wedged between the ram and the walls of the magazine, jamming the ram.

Accordingly, the objects of the invention are to provide novel and improved methods and apparatus for joining metal particles together into a useful product while maintaining the metal in its solid state.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims taken in conjunction with the accompanying drawings.

### DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic flow diagram showing the process of steel formation of this invention;

FIG. 2 is a cross-sectional view of a schematic drawing showing the feed magazine and harmonic press of the invention;

FIG. 3 shows a slightly-modified form of the feed magazine and bale configuration as compared with FIG. 2;

FIG. 4 is a cross-sectional view of the magazine and ram on an enlarged scale and as seen from the plane indicated by the line 3—3 of FIG. 3;

FIG. 5 is an exploded, perspective view showing the orientation of two bales and a cake of thermite material prior to welding the two bales with the thermite material;

FIG. 6 is a somewhat schematic view of the forging press utilized in this invention;

FIGS. 7—10 are diagrammatic views showing the path of anvil travel during the forging cycle of this invention;

FIG. 11 is a modified form of anvil support for achieving the rates of strain utilized in this invention;

FIG. 12 is a rate of strain table; and,

FIG. 13 is a cross-sectional view of the funnel portion of the magazine of FIG. 3 as seen from the plane indicated by the line 13—13 of FIG. 3.

### THE OVERALL PROCESS

FIG. 1 is a flow diagram of the process of solid state steel conversion. A transport car is shown schematically at 10. The transport car 10 is used to deliver scrap to and then charge it into a baler 11. In the baler 11, the scrap, which is an admixture of random sizes, is compressed by a pressure of the order of 1,000 to 7,500 pounds per square inch until it is from 20 to 65 percent densified and preferably approximately 35 percent dense when the bales are to be joined by welding. By these percentages, it is meant that scrap is typically formed into a bale in the shape of a rectangular solid with a preferred 35 percent of the volume of that solid being steel. Thus, the bales are compressed to a condition for transport from the baler when they weigh from 100 to 300 pounds per cubic foot.

The baling of an admixture of randomly oriented scrap of random sizes is highly important to the performance of the process of this invention. As will become more apparent presently, the baling causes the scrap pieces to become physically intertwined and interlocked to provide a bale having an inherent strength and rigidity. The strength and rigidity not only serves a more conventional function of facilitating the transport of the scrap in a condensed way, but also, more importantly, is a major factor in inhibiting longitudinal dissipation of impact forces during a subsequent forging operation.

Bales 13 are discharged from the baler 11 onto a conveyor 14. The conveyor 14 transports the bales 13 to a two-zone furnace shown generally at 15. As the bales 13 pass along the conveyor 14, they are preheated by exhaust gases emanating from a plenum 17 fed by exhaust gases from the furnace through a conduit 18. Preheated bales are fed into a first furnace zone 20 where they are heated from 1,000°F. to 1,200°F. in an inert atmosphere. Heated bales are then transported to a second zone 21 where they are heated to from 1,200°F. to 2,000°F. in a reducing atmosphere. The advantages of these atmospheres are described in greater detail in the referenced concurrently filed application.

Hot bales, identified by the numeral 22, are fed along another conveyor 23 under a hood 24 supplied by escaping oven gases. The hot bales 22 are maintained in the oven atmosphere until condensed to a solid slab. A stack 25 is provided to deliver furnace gases from the hood 24 to the furnace near its inlet or feed end and to the plenum 17 used for preheating the slab.

A magazine is shown generally at 28. The magazine 28 has a side load opening 29. When the heated bales 22 traveling along a conveyor 23 are aligned with the load opening 29, a transfer mechanism (not shown) is used to shift the heated bale 23 laterally off the conveyor 23, through the load opening 29 and into the

magazine 28. As will be described in greater detail presently, the magazine is equipped with a ram (not shown) that is actuated by a ramrod, a portion of which is shown at 30.

A plurality of heated bales are fed into the magazine as indicated by the dashed lines 31. The ram forces the bales along a feed path to the right as seen in FIG. 1. The bales are forced through a funnel portion 32 of the magazine and thence into a forging station 33 of a hot forming harmonic forging press 34.

The hot press 34 is used to reduce the bale until it is a solid mass of steel and thereafter to continue the reduction until it has been reduced by about 30% from its thickness when it becomes solid. As is described in greater detail in the referenced prior applications, the hot press 34 has side restraints of a width equal to the width of the original bale dimension. Accordingly, in compressing the bale until it is a thin solid slab, the thinning result in compaction and elongation, not widening.

Because of the operation of the magazine 28 which will be described presently, the finished slab coming out of the harmonic press 34 is a continuous slab indicated at 35. This continuous slab is shown being transported along a roller table 36 for further processing into strip steel or other finished product.

#### FEED MAGAZINE

Referring now to FIG. 2, a feed magazine is shown generally at 40. The feed magazine 40 corresponds to the feed magazine 28 of FIG. 1 with the exception that it has a top load opening 41 rather than a side load opening 29 as shown in FIG. 1.

The feed magazine 40 is shown with a plurality of bales 42 positioned in it and a further bale 43 in the process of being delivered to the load opening 41. A ram 44 and its connected ramrod 30 are shown in the retracted position for the bale-supplying operation.

The magazine 40 has a base bale supporting structure 45. The base bale supporting structure defines a guide path for the bales in their feed from the left to the right as seen in FIGS. 2 and 3.

The magazine 40 has a top structure 46 which includes the load opening 41. The magazine 40 also has side structures 47, 48 which are fixed to the base and top structures 45, 46. The structures 45-48 together provide a perimetral confinement for the bales as they are forced along their guide path by the ram 44.

FIG. 4 is a sectional view of the magazine of FIG. 3 as seen from the plane indicated by the line 4-4. While the magazine of FIG. 3 differs somewhat from the magazine of FIG. 2, in the plane of cross section of FIG. 4 they are identical.

As shown in FIG. 4, the four structures 45-48 are an integral tube. Internal walls 50 defined by the structures are of serrated configuration. The perimetral surface 51 of the ram 44 is of a complementary serrated configuration. Thus the ram 44 has serrations with lands 52 which project into grooves 53, of the wall structures and vice versa.

The functions of the serrations are to prevent pieces of scrap from the bale developing a wedge-like action between the ram and the walls of the magazine and thereby jamming the feed operation of the magazine. More specifically, if steel pieces in the bale tend to project from the bale, as they will especially under the compressive forces applied by the ram, their outward

movement will be limited by the lands of the wall 53. Since the lands of the ram project perimetally outwardly past such scrap pieces, they will cam the scrap pieces inwardly. Thus, the serrations prevent a wedging action and a wedge-like build up of scrap pieces between the ram and the surrounding magazine walls.

In FIG. 3, bales 55 are configured somewhat differently from the generally cubicle bales 42 of FIG. 2. To accomplish this, inserts are placed in the baler 11 so that recesses and projections, are formed on the bales that interfit when the bales are pressed together. This assists in producing a finished slab without any weakness along a parting line where two bales have been joined.

The avoidance of any weakness along the bales where bales are joined can be further enhanced by welding the bales together. More specifically, and referring to FIG. 5, a pair of bales 56, 57 is shown. A cake or package 58 of a mixture of thermite and steel powder is interposed between the bales. When the bales 56, 57 are inserted in a magazine hot and compressed together by the pressure of a ram, the thermite will ignite and effect welding at spaced locations between the bales 56, 57. It is important that the welding be only at spaced locations so that the jointer between the bales 56, 57 is somewhat porous in nature like the bales. Thus, when the weld passes through the compression station, the weld joint will behave in a manner virtually identical to the bales themselves.

In its preferred form, the cake 58 is formed by forming an apertured body of steel powder by known powder metallurgy techniques. The apertures are then filled with thermite. This approach assures spaced welds between the bales and prevents welding of the bales to the magazines.

Referring again to FIG. 2, the top and bottom structures 46, 45 have tapering portions 92, 93 adjacent and the outlet end of the magazine and near the harmonic press 34. Corresponding taper portions are preferably provided in the side structures 47, 48 and not shown in FIG. 2, but one of them is shown at 98 in FIG. 5. These four tapering portions define a magazine funnel section. This funnel section provides a precompression zone in which the pool of precompressed metal, which has been mentioned previously and will be described in greater detail presently, is formed and controlled.

Referring to FIGS. 3 and 13, movable top, bottom and side funnel portions 95, 96, 97, 98 are shown. Reciprocating drives in the form of eccentrics 110, 111, 112, 113 are connected to the top, bottom and side funnel portions 95-98 respectively. These eccentrics are operated in synchronism with a harmonic press so that the funnel portions 95-98 are moved out of contact with the bales in the magazine during the feed portion of a press compaction cycle. Thus, the difference between the magazine 40' of FIGS. 3 and 13 and the magazine 40 of FIG. 2 is that the funnel portions of the top, bottom and side structures of FIG. 3 are designed to be out of contact during the feed portion of a cycle. Moving the funnel portions facilitates feed of the bales. The funnel portions are returned to compressive contact at other times in the cycle, especially when forces are transmitted laterally through a workpiece.

Again referring to FIGS. 2 and 3, the cycling of the feed of further bales to the magazine should be timed with the feed of a bale to the anvils. Thus, in FIG. 2, the ram 44 is retracted and a further bale 43 is being fed.

Three bales 42 are shown in the magazine with the lead one of those extending into the funnel. A bale on the downstream side has already entered the anvils so that the self-feed action is occurring and the ram can be withdrawn without interfering with the compaction operation occurring at the anvils.

The three bales 55 shown in FIG. 3 have not progressed along the magazine to the extent of the bales 42. Withdrawal of the ram 44 for the feed of further bales in FIG. 3 will wait until the bale being fed into the anvils as shown in FIG. 3 is further fed in, so the self-feed action has fully commenced.

It will also be appreciated that the magazine with its ram can function as a baler. Accordingly, during the replenishment cycle as shown in FIG. 2, instead of pre-baled metal being fed, preheated scrap of the appropriate temperature can be passed through the load opening 41 and then compressed by the ram 44 so that the magazine serves as a baler as well as a feed magazine.

### BALE COMPACTION

FIG. 6 is a vertical sectional view of the harmonic press 34. A pair of eccentric shafts 60, 61 are journaled in a frame. Gears (not shown) are connected to the shafts to drive them in synchronized and opposite rotation.

The shafts 60, 61 have eccentric central portions 62, 63, respectively. These eccentric portions are each cylindrically contoured and each has an axis which is offset from the axis of its shaft so that on rotation of the shaft, the axis of the eccentric portion orbits about its shaft axis. A pair of platen supports 65, 66 are journaled on the eccentrics 62, 63, respectively. Platens 67, 68 are carried by the platen supports 65, 66, respectively.

Upper and lower restraining rods 70, 71 are provided. The restraining rods 70, 71 are pivotally connected to the frame of the press at 72, 73 and to the platen supports 65, 66 at 74, 75 respectively. This connection to the platen support connects the restraining rods to the platens to control the movement of the platens during a forging operation.

The arms 70, 71 include adjustment nuts 77, 78 for varying the lengths of the arms. As shown, this may be a manual adjustment. Obviously, servo motors may be mounted on the adjustment nuts to effect remote control and automatic adjustment.

The pivots 74, 75 ride in curved slots 79, 80 in platen attachment blocks 81, 82. The pivots may be secured in any suitable manner in an adjusted position such as by nuts. Alternately, servo motors, or other remotely-controllable mechanisms, can be used to adjust the arm-to-platen pivots.

The adjustment of the frame-to-arm pivots 72, 73 is shown as controlled by a lead screw 84. The lead screw 84 has worm portions 85, 86 which threadably engage upper and lower adjustment blocks 87, 88. These adjustment blocks are suitably guided in the frame and move up and down to achieve the adjustment of the pivots 72, 73. The lead screw 84 is rotationally driven by motor 89 to provide synchronous adjustment of the pivots 72, 73. Delivery pinch rolls 90 are provided for assisting in removing a finished slab strip 35.

Adjustment of the pivots 72-75 controls the movement of the anvils 67, 68. Thus, movement of the anvils by rotation of the eccentric shafts is modified by the

constraint imposed by the tensioned control rods 70, 71. More specifically, if the frame pivots 72, 73 are moved toward one another and the anvil pivots 74, 75 away from one another so that the constraining rods 70, 71 generally parallel the path of the workpiece, a movement of the anvil relative to the workpiece path of travels becomes a very thin ellipse. This thin ellipse has a major axis which approaches being perpendicular to the path of travel.

As feed of a bale is commenced, the control rods are positioned for this thin ellipse so that the impaction forces imposed are predominantly vertical with a slight horizontal moment along the horizontal path of travel. As the lead edge of a bale advances through the anvils, the anvil pivots 74, 75 are brought toward one another and/or the press pivots 72, 73 are moved away from one another so that the control rods 70, 71 are then at a more acute angle with the path of workpiece travel. This increases the horizontal component of the movement of any point on the anvil so that there is greater horizontal movement at any point on the anvil than vertical. This variation in the shape of the path which any point on the anvil transcribes as the control rods are adjusted is described in greater detail in the referenced prior applications.

Even though the horizontal component is increased, it has been discovered that the vertical movement of anvil portions can be magnified during the small, approximately 30°, segment of a revolution in which the anvils are actually performing work on the workpiece.

More specifically, viewing FIG. 6, the upper shaft 60 is rotating in a clockwise direction while the lower shaft 61 is counterclockwise. The eccentric action of the shafts coupled with the constraint of the control rods 71, provides a compound lever effect which causes a rocking action of the anvils relative to the workpiece, in addition to the generally elliptical anvil travel.

FIG. 10 shows the position of the anvil 67 when the eccentric portion 62 is in its most elevated position, assuming the workpiece travel horizontal. The anvil pivot and frame pivots 75, 73 are in central positions, vertically speaking. As the eccentric rotates 90° counterclockwise, the anvil moves to the position of FIG. 7. A further 90° clockwise rotation is depicted by the position shown in FIG. 8 which is the position of the anvil at the time when the eccentric is in its lowermost position. FIG. 9 shows the position of the anvil after a further 90° rotation from the position of FIG. 8.

The work on the workpiece is performed, as indicated above, during about 30° of arc. This 30° of arc is predominantly during the time the anvil is moving from its position of FIG. 9 to its position of FIG. 10 but it also occurs as the anvil is moving from its FIG. 8 to its FIG. 9 position. Any point toward the right, as viewed in FIGS. 8, 9, and 10, of the anvil, such as point 115, has moved a greater vertical distance than have other points further to the left, such as point 116 which is at a lower part of the anvil. This relatively great vertical movement is most pronounced if one compares FIG. 8 and 9.

It will be seen that this rocking action causes relatively great vertical movement of upper and lower bull-horn members 119, 120 which are secured to the anvil supports 65, 66 FIG. 6. The rocking action also results in the application of forces which have substantial hori-

zontal components in directions opposite the path of workpiece travel.

The lower shoe 68 has a chamfer 123 at its outlet end. A corresponding chamfer is provided on the upper shoe 67 but is not visible in FIG. 6. The purpose of this chamfer is to avoid contact of a trailing edge of the anvil as it rocks and rotates from the position of FIG. 7 to the position of FIG. 10.

Through the provisions of the funnel in the compaction zone at the outlet end of the magazine and the precompaction which has been previously mentioned, metal in that zone becomes somewhat more dense than in the bales further to the right as seen in FIG. 6 in the magazine. This more dense metal becomes further compacted by these horizontal forces applied in a direction opposite the workpiece travel so that a pool indicated by the dashed lines 121 in FIG. 6 of relatively dense but not fully compacted metal, is developed on the feed side of the harmonic press.

As an examination of FIG. 6 will show, the pool is hemi-toroidal in shape. This hemi-toroidal shape is developed because the temperature of portions of the bales near the surface is higher than central portions. Since the surface portions of the bales are hotter, they are more plastic and extrude rearwardly more than the central, cooler portions. The bale temperature is not uniform because the bales in the preferred heating step do not undergo a soak period.

As has been stated previously, this pool 121, once developed is, with proper control, stable in size. Thus, there is continuous replenishment of the pool by further scrap material as it is fed so that the pool size is relatively constant.

As has been indicated, in addition to peripheral restraint and rate of strain control, the size of the pool can be controlled by varying the rate of feed of the workpiece. Expressed another way, control of the size of the pool and therefore control of the extend of rearward dissipation of compressive forces can be effected by adjusting the volume of material passing through the press.

This volume control can be achieved by varying the position of the control rods 70, 71 to increase the horizontal feed component of the anvil motion. It can also be achieved by adjusting the spacing of the anvils to control the amount of material flowing through the press.

In connection with volume control, it should be appreciated that with a solid state transformation of scrap or other small-sized material to a solid, longitudinal dissipation of forces is different than in a conventional rolling mill or other compressive action. One reason for this difference is the feed rate of the workpiece is controlled and metered by the harmonic press. Another reason is the solid material on the output side of the press has greater resistance to longitudinal force than does the porous material on the feed side. With conventional rolling techniques, compression results primarily in elongation of the workpiece on the output side of the mill. As we have noted, the press in this instance controls feed rate so that elongation on the output side of the press will not occur. Thus, volume control is primarily a function of the spacing of the anvils and the horizontal feed component in the motion of them.

The total effect of this precompaction in the funnel portions coupled with further compaction by the bull-

horns 119, 120 and thorough densification by the anvils 67, 68 results in bales being reduced to of the order of one-third of their original dimension in a single pass through a harmonic press. Thus, in a single pass through the press of FIG. 6, there is a transition of porous bales to full, dense, intimately welded and united slabs of steel. This obviates, in most cases, the need for cold harmonic press compaction or a second pass through a hot harmonic press as is taught in the referenced prior applications.

Where the magazine is used because the metal is fed continuously and while hot into a strip mill, any slight imperfections in the slab which might occur will be perfected in the strip forming operation.

In FIG. 11, an alternate technique for achieving this described rocking or "duckbill" action of the anvils is shown. Here the anvil 68' is offset to the right as viewed in the drawing so that forces applied by the eccentric do not achieve the balance of the anvil of FIG. 6 during the force application portion of a cycle. This results in a rocking of the anvil relative to the workpiece and effecting a result similar to the result achieved with the control rods 70, 71.

#### RATE OF STRAIN

As the referenced prior cases teach, it is desirable for the application of welding forces to be accomplished by high-speed, sharp impaction of a workpiece during the slab formation operation. It has now been recognized that the optimization of force application requires a control of the extrudability or the plasticity of the workpiece. Thus, if good, thorough welding is to be effected, it is necessary to control the loss of force through extrusion or plastic flow of the workpiece. The control of extrusion or plastic flow is a function of: (a) the temperature of the product; (b) the degree of solidity of the workpiece; and (c) rate of strain.

Since three variables affect extrusion, an analysis of one of them, rate of strain and how it is derived, requires the other two be considered constant. Thus, the discussion will assume a constant temperature and that the bale is in a solid or virtually solid condition.

In analyzing rate of strain, it is also well to recognize why rate of strain is analogous to, but different than, strain rate and thus the two cannot be correlated. The reasons that one cannot correlate rate of strain to strain rate are:

A. The peculiar path of travel of the anvils which, after the initial feed portion of the cycle is, as we have seen, a relatively flat ellipse with a substantial horizontal component.

B. The porosity of the workpiece.

C. The press is equipped with side restraints which result in a substantial increase in stress as contrasted with conventional presses or rolling mills.

D. There is a temperature gradient in the workpiece because there is no "soaking" time in the bale heating as is described in greater detail in the concurrently-filed copending and referenced application.

Rate of strain is a function of force and time. It is derived from the formula  $RS = (V/TB)$  where:

RS equals rate of strain;

V equals the vertical travel of a selected point on the anvils;

T equals the time that the selected point will be in work-performing engagement with the workpiece.

This is derived by first determining that portion of a platen revolution where there is workpiece contact. For example, assuming the point selected is in engagement with the workpiece for 30° of the 360° rotation of the eccentric, the point will be in engagement with the workpiece for 1/12 of a revolution; i.e., (30°/360°). Thus,  $T$  is derived by the formula:

(Angle of arc of workpiece contact/360) × Rotational speed of Platen.

$B$  equals the beginning thickness of the workpiece. To derive

$B$  for a harmonic press of the type disclosed in the present application, one takes one-half the beginning thickness of the workpiece.

As examples of the application of the above formula, let us assume an initial bale thickness of 4.8 inches so that the value  $B$  for a half bale thickness is 2.4 inches. Assuming an eccentric with a radius of 1-½ inch, we find that with the anvil pivot points 74, 75 and the press pivot points 72, 73 both relatively widely spaced, a point corresponding to the point 115 (FIG. 6) will move 0.156 inch vertically. If the eccentric is slowed to 2.5 revolutions per second as a bale is initially fed into the press and the point 115 will engage the bale being fed for 25° of rotation. Under these conditions, the strain rate is 2.3 which is derived by

$$RS = 0.156 \text{ inch} / [(25^\circ/360^\circ) \times 0.4 \text{ sec.} \times 2.4 \text{ inches}] = 2.3 \text{ sec.}^{-1}$$

An analysis of the formula will show that rate of strain can be increased by either increasing the vertical travel  $V$  or the speed of rotation. It can also be increased by decreasing the arc of contact which thus decreases the time in which the forces are applied. Further, the rate of strain increases as the thickness of the workpiece decreases.

Thus, if, as the initial feed progresses, the pivot points 74, 75 are moved closer together and the contact arc increases to 36°. This changes the ellipse to provide a vertical deformation component of 0.406 inch and the rate of strain is increased to 4.1 sec.

$$RS = 0.406 \text{ inch} / [36^\circ/360^\circ \times 0.4 \text{ sec.} \times 2.4 \text{ Inch}] = 4.1 \text{ sec.}^{-1}$$

It has been found that by moving the press pivot points 72, 73 closer together in addition to maintaining the anvil pivot points 74, 75 close together or moving them even more closely together, the rocking motion of the anvil is increased and the vertical component is also increased. Thus, to achieve high rates of strain in excess of a desired 4, the press pivot points 72, 73 are moved more closely together rather than further apart as suggested in the prior referenced cases. The value of vertical travel can be increased, for example, to 0.88 inch, with the specific example we have given, which also results in a slight increase in the arc of contact to 40°. When so positioned:

$$RS = 0.88 \text{ inch} / [40^\circ/360^\circ \times 0.4 \text{ sec.} \times 2.4 \text{ inch}] = 8.2 \text{ sec.}^{-1}$$

At other points, say the point 116, the strain rate becomes very high. This is true because at that point (a) the workpiece is thin and (b) the proportion of the workpiece along the feed path but behind the point of impaction is solid, providing greater resistance to rearward dissipation of forces than does the semi-solid

pool. Accordingly, with the examples we have given, strain rates on the order of 4-24 should be achieved beneath the point 116 as the desired reduction of about 20 percent beyond the thickness when a solid piece was first achieved is carried out.

FIG. 12 is a table showing various strain rates calculated according to varying conditions and according to the formula  $RS = (V/TB)$ .

## SUMMARY

This is disclosed:

A. A novel feed magazine to achieve a continuous slab output.

B. Precompaction prior to the harmonic press full compression station. This is achieved in part through the use of a feed funnel portion which may be provided when the feed magazine is not used.

C. The control of the anvils to achieve a rocking action increasing vertical motion with a compound lever action.

D. The control of rate of strain.

Thus, it has been recognized that, theoretically an ideal compaction of the material would have forces which were either only perpendicular to the path of workpiece travel or along that workpiece travel. It has now been recognized that this ideal is not achievable and that the conversion of scrap or other small metal pieces to a solid slab can be optimized by controlling (1) the feed rate or volume, (2) controlling the rate of strain and (3) confining the material being fed to the press so that a controlled pool of relatively dense material is developed on the feed side of the press.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example, and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. The process of forming a metal body from small pieces of metal which have been secured together to define a workpiece said process comprising:

a. feeding said workpiece while heated to from 1,200° F. to 2,350° F. along a feed path of travel to a work station;

b. compressing said heated workpiece at the work station by repetitively impacting the workpiece to weld said pieces together thereby forming a product while maintaining the pieces in a solid state condition; and,

c. controlling the deformation of said workpiece by forces transmitted from said station along said feed path by perimetally constraining the workpiece at locations along said feed path.

2. The process of claim 1 wherein the perimetral constraint completely surrounds the workpiece in at least one plane transverse to said feed path.

3. The process of claim 1 wherein the compressing of the workpiece is accomplished with a harmonic press.

4. The process of claim 3 wherein the compressing is continued until the product is a firmly united, solid, unitary slab of metal.

5. The process of claim 1 wherein the feed path is defined by a magazine and a plurality of bales of pieces

are positioned in the magazine and sequentially fed to said station to provide the workpiece such that the product produced is formed from more than one of the bales.

6. The process of claim 5 including the step of welding the bales together while in such magazine.

7. The process of claim 6 including the step of inserting quantities of thermal fusing material between bales in the magazine and thereafter effecting such welding by pressing the bales together in the magazine with said thermal material therebetween.

8. The method of converting random-sized small pieces of steel to a steel body suitable for use in a manufacturing operation while maintaining the steel in a solid state comprising:

- a. baling the random-sized pieces and compacting the pieces until the bale is at least 20 to 65 percent solid;
- b. heating said bale to from 1,200°F. to 2,350°F.;
- c. feeding the bale along a feed path to a compression station;
- d. thereafter compressing the bale at the station by repetitively impacting the bale while perimetally confining the bale in planes of impaction until a time when it becomes solid and substantially free of voids and then continuing to compress the solid bale; and,
- e. perimetally confining the bale at a location along the feed path and near said station.

9. The method of claim 8 wherein the impaction is performed with a harmonic press having opposed platens and side restraints.

10. The method of claim 8 wherein the impaction is performed with a pair of opposed, oppositely-acting platens impacting opposed outer surfaces of the bale while other outer surfaces of the bale are confined against lateral outward movement as the bale is impacted.

11. The method of claim 8 wherein said bale is impacted with a platen achieving a rate of strain of at least 4 whereby the sharpness of the impaction blow permits inertia of rest of the bale to contribute to the minimization of longitudinal dissipation of its impact forces.

12. The method of claim 8 wherein the impaction is at rates of strain in accordance with the table of FIG. 12.

13. The method of claim 8 wherein the peripheral confinement is achieved with members that surround the bale in at least one plane transverse to said feed path.

14. The method of claim 13 wherein the members are tapered at angles of 5° to 15° with said feed path and wherein said taper is inward in the direction of workpiece travel whereby the members act as funnels.

15. The method of claim 13 wherein the members are reciprocated in paths transverse to said feed path whereby to facilitate a feed portion of an impaction cycle.

16. A method of forming a continuous body of solid metal from particulate metal, comprising:

- a. densifying particulate metal to form a porous body;
- b. progressively densifying said body by repetitively impacting said porous body in a press at a zone of impaction while said particles are confined against movement in at least one direction whereby said particles are welded together by molecular migra-

tion while kept in solid state condition, said forces being applied such that a pool of controlled size of substantially densified metal is formed closely adjacent to and in advance of said zone of impaction, said pool providing a supply of more thoroughly homogeneous, non-porous metal for the impaction zone to insure complete densification of the total body, said body being in the heated condition in the range of 1,200°F. to 2,350°F. during said impaction.

17. The process of claim 16 wherein the size of said pool is controlled by adjusting the volume of particulate metal flowing through said impaction zone.

18. The process of claim 17 wherein said press includes at least one compressive member and the size of said pool is also controlled with said compressive member achieving a rate of strain from 4 to 12 calculated by the formula  $RS = (V/BT)$  wherein:

$RS$  is rate of strain;

$V$  is the vector of member along a path normal to the feed path;

$T$  is the time the member is in engagement with the workpiece per cycle; and,

$B$  is the thickness of the workpiece compressed by the member.

19. The process of claim 16 wherein said press includes at least one compressive member and the size of said pool is controlled with said compressive member achieving a rate of strain from 4 to 12 calculated by one formula  $RS = (V/BT)$  wherein:

$RS$  is rate of strain;

$V$  is the vector of member along a path normal to the feed path;

$T$  is the time the member is in engagement with the workpiece per cycle; and,

$B$  is the thickness of the workpiece compressed by the member.

20. The process of claim 19 wherein said press includes two compressive members and  $B$  equals one-half the workpiece thickness as measured in a plane intersecting a location in a moving workpiece wherein the workpiece has just reached substantially solid condition.

21. The process of claim 20 wherein compression is performed by compressive members which are anvils of a harmonic press.

22. A method as in claim 21 in which said anvils are carried by said press so as to have at least 60 percent of the working surface thereof offset to one side of a vertical line passing through the eccentric of said press.

23. A process of forming a metal body from small pieces of metal which have been secured together to define a workpiece, said process comprising the steps of:

a. feeding said workpiece while heated to from 1,200°F. to 2,350° along a feed path of travel to and through a work station in a substantially continuous manner;

b. applying compressive welding forces to said heated workpiece at said work station by repetitively impacting the workpiece, said forces being applied in directions transverse to said feed path,

c. perimetally confining portions of said workpiece in and near said work station during the application of said forces to control the deformation of the workpiece and to establish a controlled pool of

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substantially densified metal disposed closely adjacent and in advance of said work station; and,  
d. said workpiece being maintained in solid state condition during said process.

24. A method of forming a continuous body of solid metal from pieces of particulate metal which have been secured together as a workpiece and heated to a temperature at which the pieces are still in solid state condition, comprising the steps of:

- a. feeding the heated workpiece along a path of travel to and through a work station in a substantially continuous manner;
- b. perimetrically confining portions of the heated workpiece in and near said work station to restrain expansion of the workpiece in directions transverse to said feed path and repetitively impacting portions of the workpiece in said work station in order to apply compressive welding forces in directions

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transverse to said feed path to weld the pieces into a solid homogeneous mass and to establish a pool of substantially densified metal is in advance of said work station.

25. The method of claim 24 wherein said compressive welding forces are applied by oppositely acting relatively moveable platens which engage opposite sides of the workpiece to compress the workpiece and to effect feeding of the workpiece through the work station.

26. The method of claim 25 wherein the size of said pool is controlled, at least in part, by controlling the movement of said platens.

27. The method of claim 25 wherein said platens are constrained to move along substantially elliptical paths having major axes which extend longitudinally relative to the path of travel of the workpiece.

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UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 3,783,494 Dated January 8, 1974

Inventor(s) MARK E. WHALEN, et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 11, line 45, after "sec-" insert - - 1 - -  
to read - - sec<sup>-1</sup> - - .

Signed and sealed this 21st day of May 1974.

(SEAL)  
Attest:

EDWARD H. FLETCHER, JR.  
Attesting Officer

C. MARSHALL DANN  
Commissioner of Patents

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