Jan. 30, 1968 G. D. CHANDLEY ET AL 3,366,362

METAL SHAPING TOOLS INCLUDING COLUMNAR STRUCTURES

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Fig-1

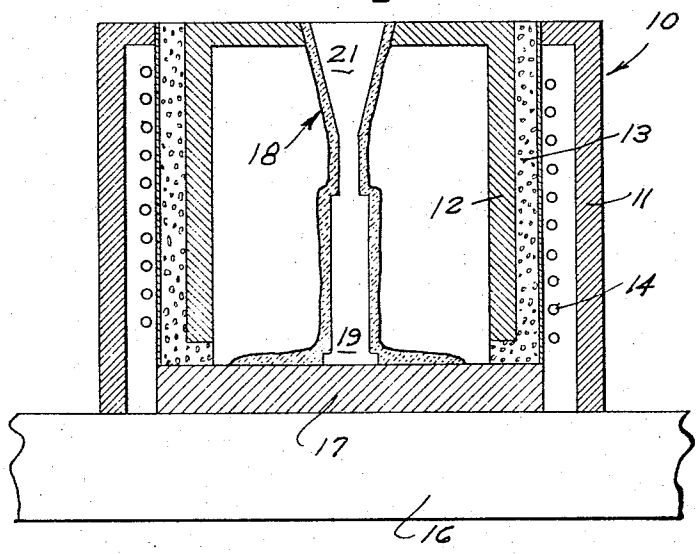



Fig-2

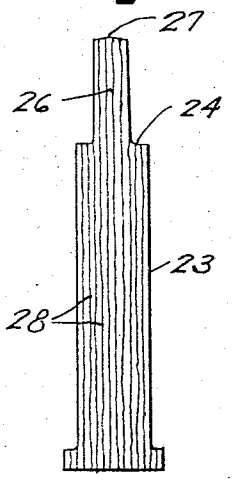
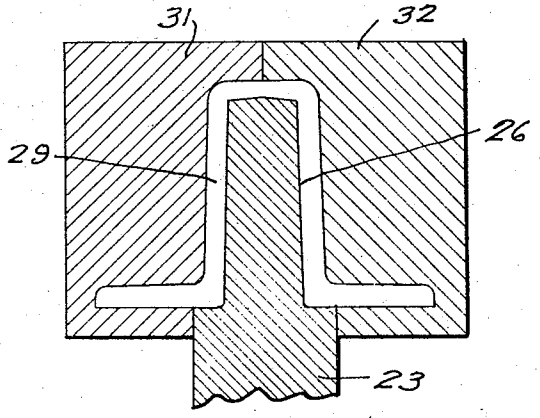



Fig-3

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# METAL SHAPING TOOLS INCLUDNG COLUMNAR STRUCTURES

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## ABSTRACT OF THE DISCLOSURE

Metal shaping tools such as cores for die casting molds wherein at least the portions of the tool which are subject to severe heat and thermal shock are composed of a columnar structure consisting of a parallel alignment of planes of maximum atomic density.

The present invention relates to improvements in metal shaping and metal working tools of increased longevity.

Existing die materials used for high temperature applications such as forging extrusion, and die casting usually have short lives. These metal working tools frequently fail by distortion, breaking, or cracking, thereby substantially increasing production costs.

The present invention relates to an improved type of metal shaping tool composed of a casting having a particular type of grain structure which gives it susbtantially greater resistance to distortion, breaking, and cracking than die materials heretofore employed.

One of the objects of the persent invention is to provide an improved metal shaping tool consisting of an integral casting having substantially improved resistance to the usual causes of tool failures.

Another object of the invention is to provide an improved molding die for high pressure injection molding composed completely or in part of a specific metallurgical structure which has been found to provide substantial improvement in resistance to severe heat and thermal shock.

Still another object of the invention is to provide an improved core structure for die molding which has a longer service life than any comparable core material in use today.

Other objects and features of the present invention will be apparent to those skilled in the art from the following description taken in conjunction with the attached drawings.

In accordance with the present invention, we provide a metal shaping tool which has at least a portion thereof subject to severe heat and thermal shock, and provide at least that portion with a columnar structure consisting of a parallel alignment of planes of maximum atomic density.

Columnar structures are formed by the unidirectional growth of dendrites during solidification. The relationship between the dendritic structure and the columnar grains is not exact. Each columnar grain is usually composed of more than one dendrite, and the number may vary from a few to several hundred. The interdendritic spacing is related to the solidification rate only. Columnar grain size, however, may be affected by factors other than the solidification process, such as ordinary grain growth. Despite these differences, the most convenient approach for the examination of columnar structure formation is through the study of the dendrites formed during solidification.

The primary requirement for the formation of a parallel dendritic structure is the presence of a unidirectional thermal gradient. When the metal first enters the mold, the initial solidification occurs at the mold wall due to a chill effect, assuming the mold wall to be below the solidification temperature of the metal. This chill zone consists of many fine dendrites having a random orientation. The initial freezing releases the heat of fusion, resulting in some temperature rise locally, arresting the chill zone formation. At the interface of the chill zone and the melt the dendrites begin to grow into the melt at a rate dependent upon the amount and depth of the supercooling.



Initially, all dendrites at the chill zone-melt interface grow at equal rates, since equal supercooling is present. However, those oriented parallel to the thermal gradient are growing into an area of continued supercooling. Those oriented unfavorably cannot advance as rapidly in the direction of the thermal gradient, since only a component of the growth velocity is aligned with this gradient. The dendrites growing parallel to the gradient, since they have already undergone some growth, will give off a latent heat of fusion, due to the freezing process. This heat of fusion increases the temperature at the base of the dendrites and decreases the amount of supercooling available for growth of the more unfavorably oriented neighbors. In this manner, the growth of the misoriented dendrites is stifled, and only those aligned with the thermal gradient will undergo significant growth.

The aligned dendrites formed will display a preferred crystallographic orientation, depending on the crystal system, and, in more complex systems, on the particular metal or alloy. This behavior can be rationalized in the following way. Crystals growing into a melt are formed with the planes of maximum atomic density forming the faces. In the face centered cubic metals, for example, the faces of the crystals would form an octohedran bounded by the (111) planes. The direction of maximum growth coincides with the maximum dimension of this octohedran, the (100) plane. It would be expected, then, that the (100) would be aligned parallel to the predominating thermal gradient and this has been observed in numerous cases. In the more simple crystal systems, the body centered cubic and the face centered cubic, the direction of preferred orientation, (100) in each case, is generally the same regardless of the metal involved. In systems of non-cubic symmetry the particular metal or alloy will determine the direction. In close packed hexagonal systems, for example, the c./a. ratio is an important factor in determining the direction of preferred orientation.

The solidification of alloys proceeds along the lines mentioned previously, but in a somewhat more complex mechanism since concentration gradients as well as thermal gradients may exist during solidification.

Casting variables affect columnar structure through their influence on the thermal or compositional gradients developed in the molds. These variables include metal superheat, initial mold temperatures, the use of chills or exothermic materials, and the alloy composition. Variation of the thermal gradients within the range of columnar formation also influences the structure of the casting. If a steep thermal gradient exists, the rapid rate of heat extraction requires rapid solidification. At the same time the relatively short supercooled layer restricts the lengths of the dendrites extending into the melts. During solidification mass transport of solute between the dendrites must take place. Since the overall solidification rate is determined by the rate of heat removal, the diffusion distances must be reduced to permit the proper distribution of solute to take place. This is accomplished by increasing the number of dendrites, thus reducing the interdendritic distances. It has been experimentally verified that as the solidification rate increases, the interdendritic spacing decreases at a rate proportional to the square root of the solidification rates.

The consequences of this behavior are evident in extended columnar structures. As the distance from the mold wall increases, the dendritic spacing also increases. This can probably be attributed partially to the elimination of unfavorably oriented dendrites, but the major influence responsible is the decrease in thermal gradients as the dendritemelt interface moves through the mold.

Comparative tests between equiaxed and columnar castings indicate that the columnar casting has marked advantages for certain applications. The high temperature strength and ductility of the columnar structures is generally superior to the equiaxed structure, and may be attributed to the preferential occurrence of gas porosity at grain boundary locations. In the equiaxed structures the gas porosity is distributed randomly, following a grain boundary pattern. As a result, intergranular fractures occurred with very low ductility. In the columnar structure the grain boundaries are oriented parallel to the growth direction. Accordingly, the porosity has little or no influence on ductility. The improvement in ductility can be attributed to several factors. The segregation normally associated with equiaxed grains is reduced by the columnar solidification process. The conditions necessary to form columnar structures are identical to those required for proper feeding. Thus, microshrinkage is almost completely eliminated. The primary reason for improved ductility, however, appears to be the elimination of grain boundaries perpendicular to the stress axis. This prevents the normally brittle intergranular type of fracture, permitting a greater amount of deformation to occur prior to failure.

Heretofore, two methods have been employed to produce die casting dies. One involves the machining of cavities in forged steel blocks, followed by heat treatment to a desired hardness. These forged blocks have a random crystallographic orientation characteristic of forged and heat treated steel blocks. When these finished dies are subjected to the high temperatures of die casting, say 1200 to 2200° F., they soften, distort and crack, causing high maintenance costs, excessive machine shutdown time, and rejected die castings.

The second method involves casting the dies to the approximate shape, heat treating the casting to the required hardness, and polishing it to the final contour desired for the die. However, such cast structures employed contain random grain orientation, typical of a heat treated steel casting, and exhibit the same deficiencies as the machined dies.

The present invention provides a die casting die, and similar metal working tools having a completely ordered orientation of atomic structure, immediately distinguishable from the cast and forged dies of the past. Through the use of the invention, we can provide a precision cast die casting die of improved service life which requires little or no machining prior to use. Neither does the material of the present invention require any heat treatment, the effects of which are lost in service of the die.

In accordance with the present invention, the entire die assembly may be composed of columnar grains, or selected areas can be directionally solidified to provide the columnar structure in those portions which are most subject to severe heat and thermal shock. In the specific embodiment of the invention illustrated in the drawings, we have shown the production of a core for a high pressure die casting assembly, purely by way of example.

FIGURE 1 is a somewhat schematic representation of a furnace assembly and mold configuration which can be employed for producing the casting;

FIGURE 2 is a view in elevation of the core, with a representation of the columnar grain structure thereon; and

FIGURE 3 is an enlarged fragmentary view in cross section showing the manner in which the core is received within the die casting apparatus.



In FIGURE 1, reference numeral **10** indicates generally a furnace assembly including an outer wall **11** composed of a suitable refractory brick material or the like, and an inner radiating enclosure **12** composed of graphite or the like. Intermediate the outer wall **11** and the radiating wall **12** is a layer **13** of insulating material. The radiating wall **12** is heated to a high temperature by a suitable means such as an induction coil **14**, although other heat sources such as electrical resistance heating and the like can also be employed.

The outer wall **11** rests upon a support **16**, and on this support there is disposed a block **17** of highly thermally conductive material such as copper. If desired, additional heat transfer means may be included within the copper block **17**, such as a circulating fluid system.

Disposed within the enclosure thus provided is a ceramic shell mold **18**, resting unsupported on the block **17**. Generally, the mold **18** has a thickness of from about $\frac{1}{16}$" to about $\frac{1}{4}$" or so, and is produced by well known techniques used for the manufacture of shell molds in precision investment casting. The mold **18** includes an open ended casting cavity portion **19** and an open ended riser cavity portion **21** into which the molten metal is introduced.

The type of furnace assembly shown in FIGURE 1 establishes high thermal gradients in the molten metal as soon as it is poured into the mold cavity. These gradients, combined with controlled heat input from the heat source such as the induction coils **14** produce unidirectional heat flow, and form columnar grain structures perpendicular to the heat sink represented by the chill block **17**.

As illustrated in FIGURE 2, the finished core consists of a casting consisting of a cylindrical portion **23**, a shoulder **24**, and a slightly tapered core portion **26** terminating in a conical end **27**. The casting consists of columnar grains **28** extending parallel to the major axis of the core, these columnar grains representing an alignment of planes of maximum atomic density in the casting.

The core of FIGURE 2 is shown in position for a die casting operation in FIGURE 3. The core is received with its tapered portion **26** centered in a molding cavity **29** defined by a pair of split die members **31** and **32**. Molten metal is then introduced into the molding cavity **29** under pressure in accordance with usual die casting techniques.

It should be understood that the die members **31** and **32** themselves can be made with columnar grain structures, as well as the core structure illustrated in the drawings.

The material to be used in the die element depends on the purpose of the die. Conventional steels can be used for moderate temperatures, and stainless steel or superalloys can be used for temperatures in excess of about 1200° F. Furthermore, it is possible to apply oxidation resistant coatings to the die elements of the present invention to prolong their srevice life even further.

To illustrate the improvements of the present invention, a die core was machined from a nickel base superalloy, and cast to provide a columnar structure with an assembly of the type shown in FIGURE 1 of the drawings. The core was used in the die casting of molten brass at temperatures of 1700° F. to 2200° F. The average core life for this particular part using conventional die cores was approximately 6000 to 7000 shots. The core of the present invention satisfactorily produced in excess of 9000 shots, and was still serviceable at that time. No scrap castings were produced because of misalignment of the core.

From the foregoing, it will be evident that the metal shaping tools of the present invention have an extended service life because of their improved resistance to high temperatures and thermal shock. It should also be evident that various modifications can be made to the described embodiments without departing from the scope of the present invention.

We claim as our invention:

1. A metal shaping tool comprising a metal working portion subject to severe heat and thermal shock by contact with molten metal, at least said portion of said tool being composed of a columnar structure consisting of a parallel alignment of planes of maximum atomic density.

2. A die element for shaping metal by die casting having a metal shaping portion consisting of a columnar structure consisting of a parallel alignment of planes of maximum atomic density.

3. A core for die casting molds consisting essentially of an integral metal casting having a columnar structure consisting of a parallel alignment of planes of maximum atomic density.

4. A molding die for high pressure injection molding having metal working portions therein subject to severe heat and thermal shock by contact with molten metal, at least said portions consisting of a columnar structure consisting of a parallel alignment of planes of maximum atomic density.

5. A molding die for high pressure injection molding consisting essentially of an integral metal casting having a columnar structure which consists of a parallel alignment of planes of maximum atomic density.

6. A die element for shaping metal by die casting having a distinct major axis of greater length than any other axis therein, said element being composed of an integral metal casting of a columnar structure in which the long dimensions of the columnar grains are substantially parallel to said major axis.



7. A core for die casting molds, said core having a distinct major axis of greater length than any other axis thereon, said core being composed of an integral metal casting of a columnar structure in which the long dimensions of the columnar grains are substantially parallel to said major axis.


**References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,008,855 | 11/1961 | Swenson | 148—1.6 |
| 3,204,301 | 9/1965 | Flemings, Jr. et al. | 164—53 |
| 3,233,294 | 2/1966 | Carpousis et al. | 164—121 |
| 3,233,295 | 2/1966 | Conroy et al. | 164—121 |
| 3,260,505 | 7/1966 | Ver Snyder | 253—78 XR |

FOREIGN PATENTS

| | | |
|---|---|---|
| 870,212 | 6/1961 | Great Britain. |

OTHER REFERENCES

India Rubber World, April 1952, pp. 80 and 81, TS 1870, I 44.



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