METHOD AND APPARATUS FOR FORMING A LIQUID-FORGED ARTICLE

Field of the Invention

The invention relates to a method and an apparatus for forming a liquid-forged article and particularly, though not exclusively, to forming a liquid-forged near net-shape article having features with high aspect ratio.

Background

Articles having features with high aspect ratio are conventionally made by methods including machining, extrusion, forging, or casting a metal such as aluminium (Al). Machining is a process that produces articles with high tolerance control and good surface finishing. However, it is time consuming and expensive and results in a large amount of material wastage, making it unsuitable as a process for mass production. Extrusion and forging are processes that can produce articles with good structural integrity. However, traditional extrusion and forging are unable to form articles requiring a high density of features having high aspect ratio, such as heat sinks having fins and pins in close proximity as shown in FIGS. 1 and 2.

Die casting (high and low pressure) is a competing technology with some form of indirect pressure during material solidification that is widely used in industry. Gravity or die casting allows articles to solidify under little or no pressure. However, articles made by gravity or die casting methods often suffer from limitations such as porosity in the article structure, for example due to high turbulence of the in-gate in high pressure die casting, or gas entrapment in gravity casting, resulting in poor mechanical

properties. Die casting is also unable to form net-shape articles having high-aspect ratio features without distortion, for example, the round heat sink with high aspect ratio fins 10 as shown in FIG. 1 where the height (h) to thickness (t) ratio of each fin 10 is greater than 40 to 1, i.e., $h : t > 40 : 1$. Furthermore, material choice is naturally limited to only casting alloys, whereas for an article to be used as a thermal management component such as a heat sink, it is desirable for it to be formed from low silicon wrought Al alloys or pure Al due to their enhanced thermal dissipating performance. However, these materials cannot be successfully cast due to shrinkage defects resulting from the casting process.

Squeeze casting or liquid forging forms articles using at least partially molten metal under direct pressure in a punch and die set. Improved article tolerances with minimized material distortion and shrinkage defects can be obtained. However, issues of porosity and incomplete part formation due to gas entrapment still remain, especially in the formation of articles having high aspect ratio features. This is even more of a problem when the high aspect ratio features are required to be relatively small in size, for example, where the thickness of the feature is 2 mm or less, as porosities in such small features can make up a substantial proportion of the feature to result in material breakage and /or part failure.

Summary of the Invention

According to a first exemplary embodiment, there is provided a method of forming a liquid-forged article. The method comprises introducing a melt into a die cavity; moving a punch relative to the die cavity such that the melt enters at least one high

aspect ratio cavity in the punch and air is released via at least one air vent insert in the punch; and exerting a forming pressure on the melt while the melt solidifies in the high aspect ratio cavity.

The method may further comprise relatively moving the punch away from the die cavity while retaining the article in the die cavity. The article is preferably retained in the die cavity by forming a retaining portion of the article within a recess provided in a retaining pin disposed in a die containing the die cavity.

According to a second exemplary aspect, there is provided an apparatus for forming a liquid-forged article. The apparatus comprises a die cavity for receiving a melt; and a punch configured to exert a forming pressure on the melt, the punch comprising at least one high aspect ratio cavity for receiving the melt therein and at least one air vent insert for allowing air to be released from the high aspect ratio cavity.

For both aspects, air is preferably released through a gas exhaust passage defined by the air vent insert with the high aspect ratio cavity. Air may further released through at least one gas vent provided in the air vent insert, the gas vent being in fluid communication with the gas exhaust passage.

The air vent insert preferably comprises a head portion and an insert portion, the head portion being configured for positioning the air vent insert relative to the high aspect ratio cavity, and the insert portion being configured for extending into the high aspect ratio cavity. The insert portion may be tapered with a decreasing cross-sectional area as

it extends into the high aspect ratio cavity.

The air vent insert may be provided with at least one gas vent, the gas vent being in fluid communication with the gas exhaust passage. The at least one gas vent is preferably provided in the head portion.

The gas exhaust passage is preferably dimensioned to prevent excessive melt flow therein for preventing clogging of the gas exhaust passage by solidified melt. The gas exhaust passage may have a length ranging between 2 mm and 6 mm, with a gap tolerance of at least 20 mm between the air vent insert and a wall of the high aspect ratio cavity.

The apparatus may further comprise a retaining pin for retaining the article in the die cavity while relatively moving the punch away from the die cavity, the retaining pin being disposed in a die containing the die cavity. The retaining pin preferably comprises a recess for solidifying the melt therein such to form a retaining portion of the article within the recess.

The apparatus may comprise a plurality of high aspect ratio cavities and a corresponding plurality of air vent inserts. The plurality of air vent inserts may be provided individually.

According to a third exemplary aspect, there is provided a liquid-forged article having high aspect ratio features obtained by forming with the method of the first aspect.

According to a fourth exemplary aspect, there is provided a liquid-forged article having high aspect ratio features obtained using the apparatus of the second aspect.

Brief Description of the Drawings

In order that the invention may be fully understood and readily put into practical effect there shall now be described by way of non-limitative example only exemplary embodiments of the present invention, the description being with reference to the accompanying illustrative drawings.

In the drawings:

FIG. 1(a) is a schematic side view illustration of an article having high aspect ratio features, i.e., a round heat sink having tapered fins;

FIG. 1(b) is a schematic top view illustration of the heat sink of FIG. 1(a);

FIG. 2 is schematic perspective illustrations of examples of typical articles having high aspect ratio features, i.e., heat sinks with tapered fins, pins and radial fins;

FIG. 3 is a flow chart of an exemplary method of forming liquid-forged articles;

FIG. 4 is a schematic cross-sectional side view illustration of an exemplary apparatus for forming liquid-forged articles at a forming step of introducing a melt into a die cavity;

FIG. 5 is the apparatus of FIG. 4 at a forming step of moving a punch into the die cavity;

FIG. 6 is a schematic cross-sectional side view illustration of air vent inserts in the punch of the apparatus of FIG. 4;

FIG. 7 is a close-up view of an air vent insert of FIG. 6;

FIG. 8 is the apparatus of FIG. 4 at a forming step of relatively moving the punch away

from the die cavity;

FIG. 9 is the apparatus of FIG. 4 at a forming step of ejecting a formed article from the die cavity;

FIG. 10 is a schematic side view illustration of removal of a portion of the formed article;

FIG. 11 is a schematic side view illustration of high aspect ratio features formed with flash;

FIG. 12 is perspective photographic illustrations of exemplary articles formed by the exemplary method and apparatus of the present invention;

FIG. 13 (a) is a micrograph of material grain size obtained by conventional casting; and

FIG. 13(b) is a micrograph of material grain size obtained by the present invention.

Detailed Description of the Exemplary Embodiments

As shown in FIGS. 3 to 10, an exemplary method 100 and apparatus 20 are provided for forming a liquid-forged article having at least one high aspect ratio feature with height to width ratio preferably greater than 40 : 1.

The apparatus 20 comprises a punch 22 having at least one high aspect ratio cavity 24 for forming a high aspect ratio feature 34 in a liquid-forged article 30. For articles having a plurality of high aspect ratio features 34, a corresponding plurality of high aspect ratio cavities 24 are provided in the punch 22. Each high aspect ratio cavity 24 has an internal cavity shape corresponding to a desired feature to be formed in the article 30, such as a pin or a fin as shown in the heat sinks of FIG. 2. The high aspect ratio cavities 24 may be defined by corresponding high aspect ratio features 25 provided

in the punch 22.

The apparatus 20 further comprises a bottom puller or retaining pin 44 disposed in a die 42 for part retention and ejection. In an exemplary embodiment, the bottom puller or retaining pin 44 is provided with a trapezoidally-shaped recess 46 for retaining a formed article using a dovetail fit. The punch 22 and die 42 are preferably oriented and provided as a top punch 22 and a bottom die 42.

As shown in FIG. 4, in a first step of the exemplary method 100, a melt 52 comprising an at least partially molten material for forming the article 30 is introduced into a die cavity 41 of the die 42, 102, for example, via a launder 50. The melt temperature may range from 710 °C to 750°C, depending on the material chosen.

Next, as shown in FIG. 5, the punch 22 is moved relative to the die cavity 41 to contact the melt 52 in the die cavity 41, 104, such that the melt 52 enters the recess 46 in the retaining pin 44 to form a retaining portion 36 in the liquid-forged article 30. The melt 52 is also forced to flow and enter the high aspect ratio cavities 24 of the punch 22. This is preferably achieved by bringing the punch 22 towards the die cavity 41 as indicated by the arrow 60. The ram down speed or relative speed between the punch 22 and the die cavity 41 is preferably less than 0.5 ms^{-1} to allow for thorough filling of the cavities 24 with the melt 52.

Virtually no air bubbles are trapped in or by the melt 52 that enters and fills the high aspect ratio cavities 24 as air is released or allowed to escape via air vent inserts 80 provided in the punch 22, 106. As shown in FIG. 6, each high aspect ratio cavity 24 is

provided with its own air vent insert 80 in the punch 22 to allow air to be released from each high aspect ratio cavity 24. This ensures that all the cavities 24 are fully filled by the melt 52 to virtually eliminate porosity or incomplete part formation in the article 30 when formed.

Each air vent insert 80 preferably has a head portion 82 and an insert portion 84. The head portion 82 and the insert portion 84 may be integral with each other. The head portion 82 may be accommodated in a correspondingly shaped recess 23 in the punch 22, and is preferably configured to position the air vent insert 80 relative to its corresponding high aspect ratio cavity 24. The insert portion 84 is configured to extend into the high aspect ratio cavity 24, so that the air vent insert 80 has a generally T-shaped cross-section, as shown hatched in FIG. 7. Accordingly, the air vent insert 80 may comprise, for example, a disc-shaped head portion 82 with a rod-shaped insert portion 84 for forming a high aspect ratio pin, or an elongate, substantially rectangular head portion 82 with an elongate, substantially rectangular insert portion 84 for forming a high aspect ratio fin, depending on the desired high aspect ratio feature to be formed.

The insert portion 84 is preferably tapered with a decreasing cross-sectional area as it extends into the high aspect ratio cavity 24, such that the insert portion 84 defines a gas exhaust passage 86 with the high aspect ratio cavity 24. Each air vent insert 80 is preferably also provided with at least one gas vent 88 in the head portion 80, the gas vent 88 being in fluid communication with the gas exhaust passage 86. The gas exhaust passage 86 and the gas vent 88 allow air to escape from the cavity 24 as the melt 52 enters the high aspect ratio cavity 24 in the direction shown by the arrow 66 in FIG. 7.

The air vent insert 80 is preferably made of a metal of high heat conductivity, such as a copper-based material, so that as the melt 52 comes into contact with the air vent insert 80, the melt 52 is rapidly cooled. Rapid cooling of the melt 52 prevents excessive flow of the melt 52 into the gas exhaust passage 86 that can lead to choking or clogging of the gas exhaust passage 86 or gas vent 88. Accordingly, the gas exhaust passage 86 should be dimensioned to prevent excessive melt flow therein so as to avoid clogging by solidified melt 52, while sufficiently allowing air to be released. To that end, the gas exhaust passage 86 may have a length ranging between 2mm and 6mm along the cavity 24, with a gap tolerance of at least 20 μm between the insert portion 84 and a wall 26 of the high aspect ratio cavity 24.

The punch 22 is configured to exert a forming or direct pressure of between 50 MPa and 120 MPa on the melt 52 while the melt 52 solidifies in the high aspect ratio cavities 24, 108. By exerting a direct forming pressure during solidification, stress is evenly distributed in the solidified material so that virtually all shrinkage defects are eliminated in the formed article. Releasing air via the air vents 80 and solidifying the melt 52 under direct pressure of the punch 22 results in formation of a near net-shape article 30 having high aspect ratio features 34 with virtually no porosity or shrinkage defects.

After the melt 52 has solidified, the punch 22 is moved relative to the die cavity 41 to separate the liquid-forged article 30 from the punch 22. For example, as shown in FIG. 8, the punch 22 may be retracted from the die 42 as indicated by the arrow 62, leaving behind the liquid-forged article 30 in the die cavity 41. The punch 22 can be retracted without the formed article 30 sticking to the punch 22 because of the dovetailing fit

between the recess 46 in the retaining pin 44 and the retaining portion 36 formed in the article 30. The liquid-forged article 30 is then removed or ejected from the die cavity 41 by relative movement between the retaining pin 44 and the die 42 until the formed article 30 is clear of the die cavity 41. The relative movement may preferably be achieved by moving the retaining pin 44 into the die cavity 41 in the direction indicated by the arrow 64 in FIG. 9 so that the formed article 30 is pushed out of the die cavity 41.

The article 30 may be finished by machining or cutting off the retaining portion 36, as indicated by the dotted line in FIG. 10(a) to result in the formation of a near net-shape liquid forged article 30 having features 34 with high aspect ratio as shown in FIG. 10(b). FIG. 11 shows close-ups of exemplary high aspect ratio features 70, 72 formed with flashes 71, 73 as a result of cooling of the melt 52 in the gas exhaust passage 27. The flashes 71 of a thicker feature 70 as shown in FIG. 11(a) may be removed by sand blasting or tumbling. For a thinner feature 72 as shown in FIG. 11(b) that may not be rigid enough to withstand the forces of sand blasting or tumbling, the flashes 73 may be cut or trimmed away.

Exemplary liquid-forged articles such as heat sinks 90 having high aspect ratio fins 92 or pins 94 formed by the exemplary method 100 and apparatus 20 described above are shown in FIG. 12. As can be seen in FIG. 13 (b), the microstructural grain size of the liquid-forged articles is significantly smaller than the grain size of articles formed by conventional casting shown in FIG. 13(a). Smaller grain sizes together with virtually no porosity result in improved toughness of the liquid-forged articles over conventionally cast articles, thereby strengthening the high-aspect ratio features formed.

Whilst there has been described in the foregoing description exemplary embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations in details of design, construction and/or operation may be made without departing from the present invention. For example, where a plurality of high aspect ratio cavities 24 are provided in the punch 22, the corresponding plurality of air vent inserts 80 may be provided individually for ease of air release or may alternatively be provided as an integral unit comprising a plurality of insert portions 84 disposed on a single head portion 82 for reduced tooling costs. The plurality of high aspect ratio cavities 24 (and their corresponding air vent inserts 80) may or may not be identical, depending on the desired high aspect ratio features 34 to be formed. The liquid-forged article 30 may or may not be symmetrical.

The Claims

1. A method of forming a liquid-forged article, the method comprising:

introducing a melt into a die cavity;

moving a punch relative to the die cavity such that the melt enters at least one high aspect ratio cavity in the punch and air is released via at least one air vent insert in the punch; and

exerting a forming pressure on the melt while the melt solidifies in the high aspect ratio cavity.

2. The method of claim 1, further comprising relatively moving the punch away from the die cavity while retaining the article in the die cavity.

3. The method of claim 2, wherein the article is retained in the die cavity by forming a retaining portion of the article within a recess provided in a retaining pin disposed in a die containing the die cavity.

4. The method of any one of the preceding claims, wherein air is released through a gas exhaust passage defined by the air vent insert with the high aspect ratio cavity.

5. The method of claim 4, wherein air is further released through at least one gas vent provided in the air vent insert, the gas vent being in fluid communication with the gas exhaust passage.

6. An apparatus for forming a liquid-forged article, the apparatus comprising:

a die cavity for receiving a melt; and

a punch configured to exert a forming pressure on the melt, the punch comprising at least one high aspect ratio cavity for receiving the melt therein and at least one air vent insert for allowing air to be released from the high aspect ratio cavity.

7. The apparatus of claim 6, wherein the air vent insert defines a gas exhaust passage with the high aspect ratio cavity.

8. The apparatus of claim 6 or claim 7, wherein the air vent insert comprises a head portion and an insert portion, the head portion being configured for positioning the air vent insert relative to the high aspect ratio cavity, and the insert portion being configured for extending into the high aspect ratio cavity.

9. The apparatus of claim 8, wherein the insert portion is tapered with a decreasing cross-sectional area as it extends into the high aspect ratio cavity.

10. The apparatus of any one of claims 7 to 9, wherein the air vent insert is provided with at least one gas vent, the gas vent being in fluid communication with the gas exhaust passage.

11. The apparatus of claim 10 when dependent on claim 9 or claim 8, wherein the at least one gas vent is provided in the head portion.

12. The apparatus of any one of claims 7 to 11, wherein the gas exhaust passage is dimensioned to prevent excessive melt flow therein for preventing clogging of the gas exhaust passage by solidified melt.

13. The apparatus of any one of claims 7 to 12, wherein the gas exhaust passage has a length ranging between 2 mm and 6 mm and wherein there is a gap tolerance of at least 20 mm between the air vent insert and a wall of the high aspect ratio cavity.

14. The apparatus of any one of claims 6 to 13, further comprising a retaining pin for retaining the article in the die cavity while relatively moving the punch away from the die cavity, the retaining pin being disposed in a die containing the die cavity.

15. The apparatus of claim 14, wherein the retaining pin comprises a recess for solidifying the melt therein such to form a retaining portion of the article within the recess.

16. The apparatus of any one of claims 6 to 15, further comprising a plurality of high aspect ratio cavities and a corresponding plurality of air vent inserts.

17. The apparatus of claim 16, wherein the plurality of air vent inserts are provided individually.

18. A liquid-forged article having high aspect ratio features obtained by forming with the method of any one of claims 1 to 5.

19. A liquid-forged article having high aspect ratio features obtained using the apparatus of any one of claims 6 to 17.