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BLADE INVESTMENT CASTING PROCESS
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Fig. 1

Fig. 2

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BLADE INVESTMENT CASTING PROCESS

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5 Sheets-Sheet 3

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This invention relates primarily to the manufacture of hollow buckets for gas turbines, although the principles and procedure of the invention are suitable for the casting of other objects.

Because of the complicated shape and refractory material of gas turbine blades or buckets, the most common and most satisfactory method of manufacturing such buckets has been the investment or "lost wax" casting process. The precision of form of blades manufactured by this process has not, in the past, been altogether satisfactory.

The deficiencies of previous casting techniques become more critical when an attempt is made to apply them to the manufacture of hollow blades. For satisfactory operation, the hollow turbine blade must have a thin wall and the thickness of the wall must be accurately controlled to avoid variations in characteristics of the blades, such as vibration characteristics, and to avoid weak spots due to unduly thick wall areas and hot spots due to thick wall areas. Not only is greater accuracy required, but the difficulty of providing satisfactory patterns is much greater where the structure of the blade is tubular.

Since it is highly desirable to raise the operating temperature limits of gas turbines, and one of the most promising approaches to this is to install hollow blades which may be cooled by circulation of air or in other ways, a great deal of effort has been spent on attempts to manufacture hollow turbine vanes and blades. Because of the rigorous service conditions and the inherent characteristics of known materials which are suitable for such use, very little progress has been made prior to this invention in producing usable hollow turbine blades.

My invention provides a workable solution to this problem and makes possible the casting of accurate thin walled turbine components from the highly refractory alloys commonly employed for gas turbine buckets and the like. In brief summary, the process of the invention involves the production of a disposable pattern of a strong dimensionally stable material which is a replica of the blade to be manufactured, with allowance for shrinkage in casting, and the employment of this pattern in the well-known investment casting process. By producing the patterns by injection molding of polystyrene, identical dimensionally accurate and dimensionally stable patterns may be easily produced in quantity.

The invention also provides a solution of the problem of forming a pattern notwithstanding the complex shape of the bucket and the variations in form and dimensions of the interior passage. The application of the invention has resulted in the production of turbine buckets of much greater accuracy than those previously obtainable and eliminates the previously insuperable difficulties in the way of manufacturing satisfactory hollow buckets.

The principal objects of the invention are to provide a feasible process for the manufacture of hollow turbine elements, particularly one usable with materials which may be satisfactorily formed only by casting; to improve the characteristics of gas turbine engines; and to provide heat resisting components for such engines of better quality than have been available heretofore. Subsidiary objects of the invention are to provide improved patterns, particularly improved turbine bucket patterns; to facilitate the manufacture of such patterns; and to provide patterns which will facilitate the performance of the casting operation. Various other objects of the invention and the advantages thereof will be apparent to those skilled in the art from the subsequent detailed description of the preferred embodiments of the invention.

The turbine elements of the sort to which the process is applied are variously known as vanes, blades, and buckets. In this specification the turbine rotor elements will be referred to as buckets, the portion thereof which extends into the gas stream will be referred to as the blade, and the portion which provides a mounting in the turbine rotor will be referred to as the root. The examples described herein are all turbine bowls, although the process is equally applicable to the stationary blades or vanes and to other objects of manufacture.

Referring to the drawings, Figure 1 is a cross-sectional view of one form of blade pattern mold in place in an injection molding machine, the machine being illustrated fragmentally; Figure 2 is a sectional view taken along the parting planes of the mold with the molded pattern in place, the plane of the section being indicated in Figure 1; Figures 3 and 4 are perspective views of the two halves of the mold; Figure 5 is a side elevation of the finished pattern; Figure 6 illustrates a step in the investing of the pattern; Figure 7 illustrates the heating of the turbine bucket mold; Figure 8 is a sectional view through the mold with the blade metal cast therein; Figure 9 is an elevational view of the cast blade with the gate and riser indicated by broken lines; Figure 10 is an end view of the structure shown in Figure 9 to an enlarged scale; Figure 11 is a side view of a second form of blade pattern; Figure 12 is a perspective view illustrating the assembly of the pattern of Figure 11; Figure 13 is a side elevation of a third form of blade pattern; Figure 14 is a partial edge view of the same; Figure 15 is a perspective view illustrating the assembly of the pattern of Figure 13; Figure 16 is a side elevation of a fourth form of blade pattern; Figure 17 is a cross section of the same take on the plane indicated in Figure 16; and Figure 18 is a perspective view illustrating the assembly of the pattern of Figure 16.

While turbine buckets vary in size, contour, and means of attachment to the turbine rotor, the general nature of such buckets is well known to those skilled in the art to which this invention relates, and moreover, will be apparent from the illustrations and the succeeding description of exemplary patterns which are models of the blades formed from the patterns.

Referring first to Figures 9 and 10, one form of bucket, indicated as A, comprises a blade 21 and a root 22. The root comprises an upper section 23 which as viewed in Figure 10 is a rhomboid. The portion of the root which enters the mounting grooves in the turbine rotor comprises two prongs 24 which taper away from the portion 23. A passage 26 extends from the tip of the blade through the root 22 so that when the blade is mounted in the turbine wheel air may be circulated from within the wheel through the blade. As will be noted from Figure 10, the blade is twisted and tapers toward the tip, and the walls are of substantially uniform thickness with the result that the passage 26 varies in orientation throughout its length and is tapered, with the smaller end at the tip of the blade. It will be understood that the
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projections 24 of the base will be ground to provide serrations by which the blade is retained in the turbine wheel.

The blade of Figure 9 is formed by the employment of the investment casting process utilizing the pattern B, illustrated in Figure 5, which constitutes a replica of the bucket and core, as illustrated in Figure 31 and a base portion 32 with a central passage 36. The pattern B also comprises projections 37 and 38 from the base portion and a rod 39 extending from the part 38 to the tip of the blade 31. The elements 37, 38, and 39, which are molded integral with the bucket pattern, constitute a pattern support and riser system of the blade mold.

The pattern B is formed by injection molding of a suitable material, the preferred material being polysulfone because of its suitability for the production of accurate patterns.

The pattern is molded in a single piece by the employment of the mold C illustrated in Figures 1 to 4 and conventional injection molding apparatus and techniques. Since injection molding, including the manufacture of molds, is a well-developed branch of technology, it is unnecessary to burden this specification with a detailed explanation of the process. The mold C comprises a top cavity plate 41 and a bottom cavity plate 42, mating faces of which are shown in Figures 3 and 4. The parting plane of the blade mold follows the contour of the blade. The blade cavity 43 in the top plate conforms to the concave face of the blade and the cavity 44 in the plate 42 conforms to the convex face. The blade root is defined by the portions 46 and 47 of the mold and the face 48 (Fig. 4) of a bar 49 which reciprocates between guide blocks 51. The forward end of the bar 49 is formed with a projection 52 which enters the notches 53 and 54 in the molds to define the inner end of the blade root. The bar 49 supports the core 56 which defines the passage 36 of the pattern. The core 56 extends through the blade cavity and into a recess 57 in the plate 42 when the bar 49 is fully inserted.

The plastic material is injected through a sprue passage 58 in the top plate and flows through runners 59 and 60 formed by channels of semi-circular cross section in the faces of the cavity plates. The plastic material also flows into semi-circular grooves 61 and 62 which form the parts 37 and 38 (Fig. 5). The runner passages 60 forms the part 39 of the pattern. The ends of the passages 61 and 62 are closed by the blocks 51. Ejector pins 63 are fitted in the bottom plate 42.

Figure 2 illustrates the mold C in a sectional view taken along a plane passing through the mold material constituting the pattern B. The molding operation is illustrated in Figure 1. The top cavity plate 41 is fixed to a front clamping plate 66 in any suitable manner, this plate being mounted on the fixed die plate of the molding press (not shown). The cavity plate 42 is likewise mounted on a clamping plate (not shown), which may be secured to the movable plate of the molding machine (not shown). The bar 49 is inserted fully to put the core 56 in position and the mold is closed and held closed in the usual manner by the movable die plate of the machine. The polysulfone in a plastic condition is injected by mechanism of known type (not shown) through a nozzle 67 and the sprue passage 58 to fill the mold. When the plastic has cooled and solidified, the mold is opened, the core is withdrawn, and the ejector pins 63 are operated to knock the pattern from 60 and the investment core 61 from the moulding material. The pin 63 may be effected by automatic mechanism by known manner. The solidified sprue 68 (Fig. 1) is then cut from the pattern, completing the pattern B.

The employment of the pattern B in the casting of the blade may follow well-known techniques of the investment casting art which need not be explained in detail, since such processes have been employed previously for the casting of turbine buckets.

In brief outline, the pattern B is set up in a flask 80 and embedded in an investment material 81. This material is a refractory composition which, after being poured into place, solidifies. After the investment material has hardened, the mold D is heated to melt and burn out the polysulfone pattern, which leaves a cavity in the refractory material conforming to the desired blade and in addition a gate or sprue 82 and a riser 83 (Fig. 7). Figure 7 illustrates further heating of the mold after the pattern has been burned out. The mold is heated to a quite high temperature, of the order of two thousand degrees F., for the purpose of reducing the melting points of the alloys. As illustrated schematically in Figure 7, the mold D is being heated in an electric furnace or heater E, the details of which are immaterial since any suitable furnace may be employed.

Figure 8 illustrates the mold D after pouring of the metal to form the rough blade casting F. The pouring may be accomplished by known techniques, and after the metal has set the investment material is broken away and the gate and riser, indicated in broken lines in Figures 9 and 10, are cut off leaving the finished casting A.

It will be apparent from the description as is herein exhibited to the production of accurate turbine buckets and the like because of the characteristics of accuracy and stability of the plastic patterns formed in a permanent mold and the ability of the investment casting process to reproduce the pattern accurately and with a surface finish of high quality. The incorporation in the pattern of the gate and riser system substantially facilitates the casting operation. It will be understood that the original mold C must be dimensioned to provide for casting allowances.

The blade illustrated in Figures 9 and 10 is of such form that the mold core 56 may be withdrawn from a complete blade pattern. In many cases, the desired form of the blade and the internal passage therein is such that this is impossible. The invention also includes procedures by which patterns may be produced which are suitable for the casting of blades of such form that a core may not be withdrawn from a complete blade pattern. This objective may be attained by assembling the blade pattern from several molded parts, the arrangement of the parts being such that the core may be withdrawn from the blade portion of the pattern. This may be accomplished in any one of several ways depending upon the structure of the blade to be cast.

Assembling of the blade pattern offers additional advantages particularly with larger blades where the pattern involves heavy weights which give rise to difficulties in the injection molding process.

It is also possible, by the use of a two-piece pattern to eliminate the use of a core in the blade part of the mold and thus simplify the molding operation.

Figures 11 and 12 illustrate a blade pattern G generally similar to pattern B of Figure 5, but without the pattern for the gate and riser system. The pattern G is formed of two parts, a blade portion 91 and a base portion 92, the forms of which are shown by the drawings. These parts are molded separately, in individual cavities of the same mold if desired. The passage 93 through the blade 91 is formed by a retractable core in the manner previously described. The base portion is formed with a continuation 94 of the passage through the blade which requires no retractable core since this part may be ejected from the mold along the axis of the passage 94. It will be noted that the blade part 91 includes a flange 95 which forms the upper portion of the base when the pattern is assembled. The pattern may be assembled in any suitable manner, as by brazing the two parts together, forming a pattern for the polysulfone and pressing the two parts together.

Figures 13 to 15 illustrate a third form of blade pattern. This pattern H is for a blade in which the open-
ing through the foot is wider transversely of the blade than the opening in the blade, and the passage through the blade is greater in a direction from the leading to the trailing edges of the blade. Therefore, it is impossible to form the entire passage by a single retractable core. Also, this blade is of relatively large size and the blade root is heavy.

In this case, advantageous results are secured by molding the root pattern in two parts preferably joined along the medial plane of the root in a fore and aft direction, one half of the blade root pattern being molded integral with the blade. Referring in detail to Figures 13 to 15, the blade pattern H comprises a hollow blade 96 integral with which is one side 97 of the root. The other half of the root is formed by a separate piece 98. In this form, the internal passage 99 of the blade diverges toward the tip of the blade so that the core may be withdrawn from the tip end. Since the foot is molded in two parts, no retractable core is required therein, and the passage in the foot may be wider than the passage through the blade. The two parts are cemented together in the manner previously described to form the pattern.

Figures 16 to 18 illustrate a pattern for a hollow blade which may be molded without the use of a long withdrawable core for the blade portion. The pattern I utilizes a blade portion formed of two parts. The larger part 100 of the pattern defines one side 101 of the blade and the leading edge and trailing edge portions, 102 and 103 respectively, as well as the base 104. The other face of the blade is defined by a piece 106 which fits into recesses molded in the piece 100 so that when the pattern is assembled the outer surface is flush. The blade part 106 is integral with a flange 107 which rests on a ledge 108 on the base. An air opening 109 is formed through the base by a short retractable core, the air passage 110 through the blade being defined between the parts 100 and 106. This procedure for forming the pattern permits even greater flexibility in the form of the internal passage than those previously described since the internal passage may be of such form that a core could not be withdrawn from either end.

It will be seen that the invention thus permits great latitude in the design of blades or, in other words, is adaptable to the manufacture of blades of greatly varying form and places no significant restriction on the ultimate form of the blade. This flexibility and adaptability of the process is one of its major advantages.

The most important advantage of the process, however, lies in the fact that it lends itself readily to the production of hollow blades and provides the high degree of precision necessary for the production of satisfactory blades with thin wall sections. The description herein of preferred embodiments of the invention to illustrate the principles thereof is not to be considered as limiting the invention, since many variations within the scope of the invention may be made by the exercise of skill in the art.

I claim:

A method of casting a hollow turbine bucket, said bucket comprising a hollow blade portion with thin walls defining a passage through the blade portion and a base portion of heavier section than the blade portion and having a passage therein communicating with the passage in the blade portion, the said method comprising preparing a permanent mold including parts defining surfaces corresponding to the exterior and interior surfaces of the walls of the hollow bucket, molding in the said mold from a polystyrene plastic a pattern part corresponding to the blade portion and a part of the base portion of the bucket adjacent the blade portion, preparing a second permanent mold including parts defining surfaces corresponding to the entire surface of the remainder of the base portion of the bucket, molding in the said second mold from a polystyrene plastic a second pattern part remainder corresponding to the part of the base portion of the bucket, cementing the pattern parts together to form a pattern defining the outer surface of the bucket and the surface of the passage therethrough, and casting the bucket by an investment process utilizing the said pattern.

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