

May 27, 1958

E. C. RORK

2,835,960

METHOD OF FORGING BALANCED TURBINE IMPELLERS AND THE LIKE

Filed Dec. 12, 1955

2 Sheets-Sheet 1

Fig. 1

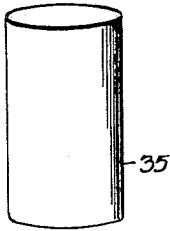
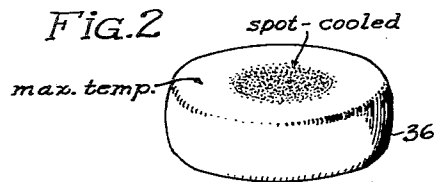


Fig. 5

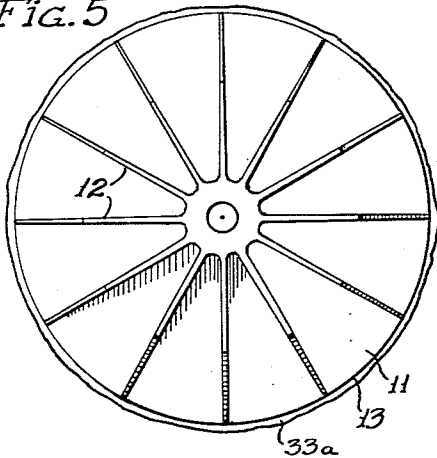


Fig. 3

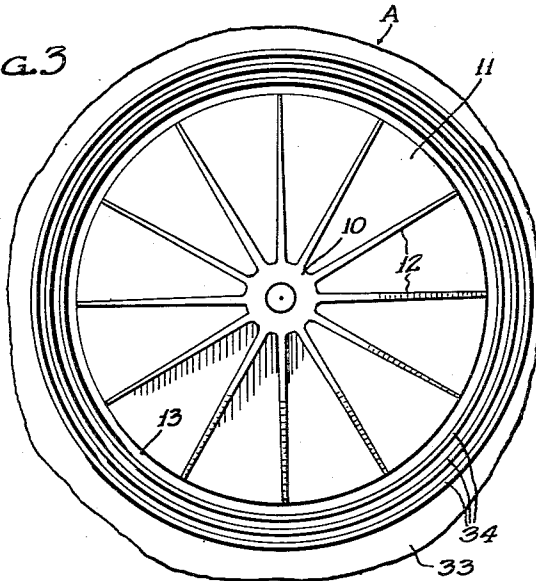


Fig. 6

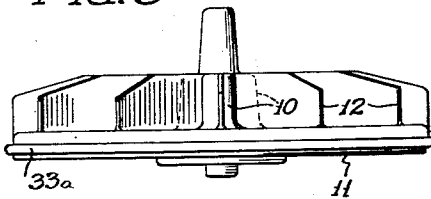
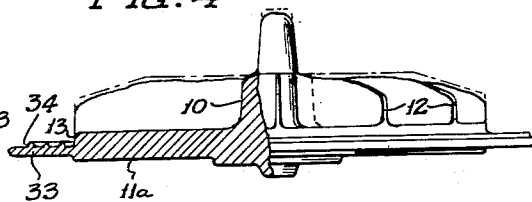


Fig. 4



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2 Sheets-Sheet 2

Fig. 11

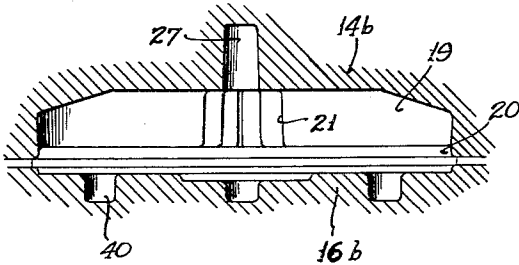


Fig. 10

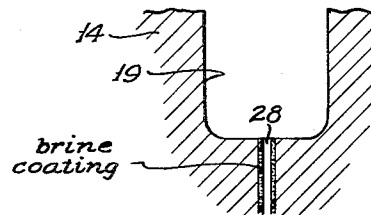


Fig. 9

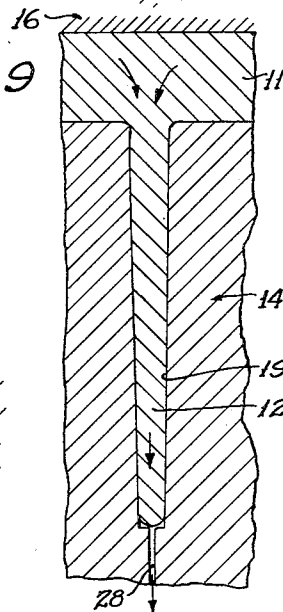


Fig. 7

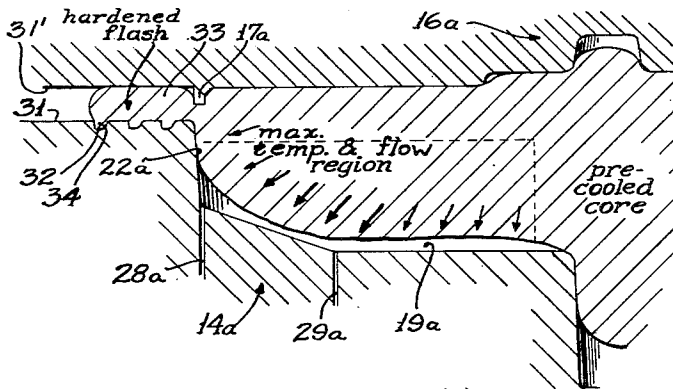
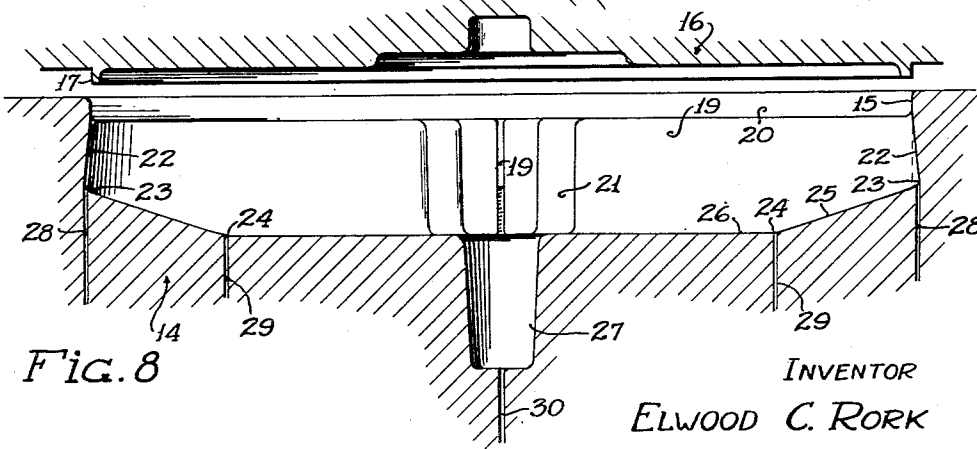


Fig. 8



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METHOD OF FORGING BALANCED TURBINE IMPELLERS AND THE LIKE

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Application December 12, 1955, Serial No. 552,493

10 Claims. (Cl. 29—156.8)

This invention relates to the die-forging art, and has as its object to provide an improved method and apparatus whereby articles of intricate cross-section, having highly extended thin-walled terminal projections, may be forged with dependable high fidelity of reproduction of the configuration of the die cavity.

The invention deals particularly with the special problems of hot die forging of articles of high density metals (e. g. high density alloy steel) as distinguished from the working of softer metals (e. g. impact extrusion of aluminum articles) where such problems are not involved.

The invention was developed especially to meet the exacting requirements for accuracy in reproduction of articles such as ultra high speed turbine wheels (impellers) for use under extremely high speed, high temperature conditions, as in the driven turbines of jet engines, turbo-prop driving apparatus, heat-absorption turbines, and superchargers, for aircraft. In such turbine impellers, designed to operate at speeds in the range between 40,000 and 150,000 R. P. M. (which to meet the requirements for efficient operation and maximum reduction in weight, have impeller vanes that are quite thin in proportion to their area and height), it has hitherto been considered impossible, in a finishing stage of forging operation, to attain the required accuracy of reproduction of the specified vane contours and dimensions, down to the fine tolerances that are absolutely necessary in order to achieve virtually perfect dynamic balance in the rapidly spinning impeller when operating. Attempts to force such impellers to finished form from stainless steel, or any other high density alloy steel or metal of similar qualities, have been wholly unsuccessful. It has therefore been considered necessary to fabricate such impellers either by machining them from solid blocks of the required metal, or by utilizing a combination of forging and machining operations in which impeller blanks having approximately the required finish contours, but with over-size dimensions, are roughed out in a block-forging step, and are then finished by machining all surfaces thereof down to the required finish dimensions. Either of these processes reaches the extremely undesirable result of removing the hard, fine-grained tough skin that is imparted to a forged surface, thereby greatly reducing the strength of the article per unit weight. Furthermore, it is only by the use of extreme care and caution, coupled with expensive time-consumption, that the machined surfaces can be finished in a uniformly smooth condition, free of surface scratches that constitute incipient fracture lines along which subsequent failures are apt to occur.

There has been a pressing need for an improved technique for forging such deep, thin-walled, intricate articles to finished form without resort to major machine finishing operations, in order to (a) reduce the heavy expense involved in such machine-finishing operations; (b) utilize the advantages of a tough, fine-grained forged skin in strengthening the article and avoiding the incipient fracture lines produced in machining operations; and (c)

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thereby obtain a considerably higher strength-weight ratio factor particularly where the article is to be used in aircraft where this factor is of paramount importance.

Despite this need, experts in the art have heretofore said that it was impossible to finish-forg an impeller or comparable article such as is contemplated by the present invention. In all prior attempts to reproduce the extremely thin impeller blades in the chambers of a forging die cavity, the blades have been imperfectly shaped, especially at their more remote extremities where they have failed to completely fill the remote crevices of the die cavity, due to hardening of the work metal before reaching and taking the impression of such remote crevices.

A particular object of the invention is to provide a method of controlling the flow of plastic or semi-fluid work metal in the chambers of a die during a forging operation, in a manner such as to reliably fill the remote crevices of such chambers, so as to attain a required high fidelity of reproduction.

In conventional forging practice, it has always been regarded as axiomatic that the larger die chambers nearest the center of the die cavity must be filled first, and that only in the final stage of the forging operation, or in the final step of a series of forging steps, can the remote crevices of the die cavity be filled. This evolves from the basic principle that metal flow is always outward and away from the center of mass of the plastic body of heated metal constituting the work blank, with maximum flow occurring in the areas of least resistance; and that the resistance is always greater along the surface of the die than in the center of the plastic mass. Accordingly, where a large percentage of the total volume of the die cavity is constituted in a series of deep, narrow chambers such as would be required for shaping a series of deep thin vanes, the above mentioned principles have defeated all efforts to extrude the various protrusions of the plastic work blank full depth into the die chambers, the flow resistance along the surfaces of such chambers being too great in relation to the thickness of the work blank protrusions that are being forced into the chambers. Thus, all attempts to forge such deep, thin vanes, utilizing the known techniques of first filling the large central chambers of the die cavity and finally pushing the hardening extremities of the work blank into the remote crevices of the deep narrow terminal chambers, have failed where the article has extremities that are as thin and extended as the vanes of a turbine impeller. According to very recent (1954) statements of foremost authorities, the most intricate, extended surface article that has been successfully forged prior to the present invention, is an airplane jet engine wheel having internal heat radiating vanes which in fact, are less than half as deep in proportion to their thickness as the vanes of the impeller which is being successfully produced by the process of the present invention.

In the forging of the softer metals, and in impact extrusion processes, there has been developed the practice of using closed dies wherein male and female die elements come together with a mating action in which the work blank is completely enclosed so as to force it to flow under pressure into the various crevices of the die. The method of this invention is of the closed die type, although flash is extruded at the periphery of the work blank, particularly in the blocking stage operation that will be referred to more particularly hereafter.

In working with high density alloy steels in forging operations, it has become a firmly held opinion, expressed by experts in the art as recently as September, 1955, in the convention of the SAE, that the more intricate shapes such as those contemplated by this invention, cannot be satisfactorily attained except by heating

the dies to within 200° F. of the temperature of the work blank, which I find must be held in a range above 1900° F. in order to obtain satisfactory results in the finish forging of such shapes. Contrary to this widely held opinion, the present invention utilizes dies that are maintained at temperatures below 800° F., as by frequently applying a jet of pressurized steam at a temperature in the range between 220° and 500°, for sweeping the die free of scale, etc., and by frequently swabbing the die with a lubricant. I find that the advantages attained by using dies maintained at such a low temperature (which may properly be referred to as "cold" dies for the purposes of this description) become an essential factor in the success that the invention has attained.

In thus departing from the principle that has been prescribed by the experts as being essential in meeting the requirements herein dealt with, the invention utilizes particular methods and means for inhibiting the peripheral flow of work metal at the flash zone without attempting to completely shut it off except in the final stages of forming.

The invention is particularly characterized by what I term "hooking" of the peripheral extremities of the vane cavities in the finishing die, in order to inhibit peripheral flow and cause the flow to back up in the deeper crevices thereof.

The invention further diverges from established practice in this field, in respect to the above mentioned principle that the filling of the remote crevices of the die cavity must of necessity constitute the final stage of the forging operation. The invention particularly seeks to avoid the restrictions on extension of surface area and reduction of wall thickness in extended protrusions, that have hitherto been imposed by such established principle.

In this respect, the invention specifically provides for reduced flow resistance in the remote crevices of the die cavity chambers, while inhibiting peripheral flow in the flash zone. Specifically, the invention provides for controlled venting of such remote crevices where gas (evolved by the action of heated work metal on the die lubricant) is trapped in such crevices by the advancing flow of the work metal. Such venting aims to induce rapid flow of the work metal to such crevices.

In thus venting the remote crevices of the die cavity, the invention establishes and utilizes a principle of controlling the trapped gas pressures that are built up in the various chambers of the die cavity by the advancing flow of work metal, and is applied by controlling the size of the vents in relation to the area of gas chambers.

The use of vents in the forming chambers of the die imposes a new problem. If the vents are too large, the plastic metal will be extruded into the vents, developing flash "whiskers" that may separate from the work blank as the dies are opened, and remain in the vents, plugging them so as to destroy their useful function, or such whiskers, if they are withdrawn from the vents and remain attached to the work blank, will be folded over at the next stroke of the drop hammer, and will be driven into the surface of the work, developing a fault therein which will impair the finish of the final article and constitute an incipient fracture area therein.

I have found it possible to solve this problem, and the invention does so, by controlling the vent area to just the proper value to achieve a satisfactory balance between such area and the other factors influencing metal flow. Considerable difficulty has been encountered in the effort to achieve such balance. As a satisfactory solution of this problem, the invention has as a further object, to provide an inexpensive method of varying the size of a plurality of vents by depositing an inexpensive coating on the internal walls of oversize vents, so as to restrict the vent area to a selected degree. Such coating must be resistant to the high temperatures and other deteriorative factors present in a die forging operation, and the invention meets this problem also.

The invention is further characterized by the use of "cold spot" areas for quick-cooling and hardening of selected portions of the work blank in advance of others, and the control of such quick cooling areas in a manner to assist in directing the metal flow where flow is most needed.

It is to be understood that the specific design of the forging die will be varied to suit the particular configuration of a specific article to be forged, but that in each case the principle of utilizing a combination of controlled vents, hook, cold spots, etc., in a "cold" open die, and of adjusting these several factors to a satisfactory relationship, one to another, is followed.

Other objects will become apparent in the ensuing specification and the appended drawings, wherein:

Fig. 1 is a perspective view of a billet of metal stock as prepared at the start of the process;

Fig. 2 is a perspective view of the "biscuit" that is evolved from the billet by a flattening step;

Fig. 3 is a plan view of the work after blocking thereof is completed;

Fig. 4 is a side view thereof, partly in section;

Fig. 5 is a plan view of the finished forging;

Fig. 6 is a side view thereof;

Fig. 7 is a fragmentary sectional view of the blocking die, with work therein;

Fig. 8 is a sectional view of the finishing die;

Fig. 9 is a fragmentary circumferential sectional view of the finish die in operation, illustrating the flows of metal and trapped gas;

Fig. 10 is an enlarged fragmentary sectional view illustrating one of the coated escape vents of the dies; and

Fig. 11 is a sectional view of a modified form of the invention.

Referring now to the drawings in detail, I have shown, as one particular example of the invention, how my improved method may be utilized in processing a turbine impeller (shown as a work blank A in Fig. 3, and as a finished forging, ready for the trimming of flash, in Fig. 5) having a hub section 10, a circular body disc 11, and a plurality of impeller vanes 12, projecting from the body disc 11, the blade sections being progressively thinned toward the periphery of the impeller indicated at 13. Blades 12 are also tapered from web 11 to the free longitudinal edges so as to be thinner at said edges, i. e., are provided with normal "draft" angle in accord with standard forging practice, to facilitate separation of the work from the die. They are quite thin in proportion to depth, the particular impeller shown having blades that average $\frac{1}{16}$ " in thickness as related to $\frac{3}{8}$ " depth, or a depth to thickness ratio of 14:1. These figures are given merely to emphasize the magnitude of the ratio of depth to thickness (rather than the specific dimensions) of an article that can be successfully forged from high density alloy steel, using by invention.

THE DIES

Male and female die blocks of a finish forging die are indicated at 16 and 14 respectively in Fig. 7. The die is of the closed type, the female die block 14 having a cylindrical rim wall 15 defining a confining chamber which is entered by the male die block (punch) 16, with a sufficiently close fit to enclose the work when the dies come together, whereby relatively high pressures are developed in the plastic work blank A, for extruding the safe into the chambers of the die cavity. The punch 16 may have a peripheral lip 17 to be received within peripheral wall 15 of female die block 14.

Female die block 14 is provided with a series of chambers 19 for shaping the vanes 12. Chambers 19 in this particular instance, constitute the terminal chambers of the die cavity that is defined between die blocks 14 and 16, branching from a flat annular chamber 20 which extends radially from a central chamber 21. Chamber

20 shapes the disc body 11 of impeller A, and chamber 21 shapes the hub 10.

At the ends of vane chambers 19, the die is "hooked," in that the end walls 22 of these chambers, instead of being flared outwardly with normal draft, are inclined in the opposite direction, so as to overhang the outermost extremities 23 thereof. This hooking of the ends of the chambers inhibits the escape of peripheral work metal from the die and promotes the backing up of the metal into the deepest crevices of the die, at extremity 23, at extremity 24, and along the bottom walls 25 and 26 of the vane chamber, where the greatest difficulty in conforming the work metal to the die cavity contours is experienced. At selected remote crevices of each vane member (e. g. at the most critical corners 23 and 24, and at the bottom of trunnion cavity 27) most difficult to reach with the work metal, gas escape vents 28, 29, and 30 are provided.

The blocking die, shown fragmentarily in Fig. 7, embodying male and female die blocks 16a and 14a respectively, is similar to the finish die with the exception that end walls 22a of vane chambers 19a are flared outwardly with normal draft, and apron 31 of female die block 14a is provided with three shallow narrow annular grooves 32 which resist the extrusion of flash 33 from the periphery of the blocking die between aprons 31 and 31'. Ribs 34 are extruded from flash 33 into grooves 32 and interlock therein as the flash hardens, to resist radial extension of the flash.

The vane chambers 19a of the blocking die are of the same dimensions and proportions as vane chambers 19, except for end walls 22a. Vents 28a, 29a, etc. are preferably utilized.

THE METHOD

Forming the work blank (biscuit)

In the practice of the method, the work billet 35 shown in Fig. 1 is prepared, as by severing a cylindrical rod of the prescribed alloy metal into sections of the correct length to give the volume required in developing the finished article, making due allowance for flash and other waste that will occur. The ends of the billet are then machined to a smooth finish, to remove saw marks that would develop into incipient fracture faults if allowed to remain, and the side of the billet is likewise finished, as by centerless grinding, to smooth to accurately cylindrical form, and to remove all surface indications (such as accrue in a rolling operation).

The billet 35 is then heated to as high a temperature as can be imparted to it without damage (i. e. to a temperature in the range of 2100° F.-2200° F. (where the material is high density alloy steel) and is placed under a drop hammer, between flat, parallel hammer and anvil dies, and flattened into the biscuit 36 shown in Fig. 2. As the result of the previous step of finishing billet 35 to remove saw marks and other roughness, which would reproduce in billet 36 if allowed to remain, the biscuit will have smooth surfaces that are correspondingly free from roughness. In flattening the billet to form the biscuit, a sufficient number of relatively light blows are struck to effect a gradual change in form such as to avoid splitting the expanding periphery of the biscuit. In some cases, reheating may be resorted to during the operation.

The completed biscuit has a diameter roughly two thirds the diameter prescribed for the finished article, and a thickness somewhat less than the sum of the maximum vane depth plus thickness of web 11. The biscuit is then descaled by a jet of steam from a steam gun.

Heating-adjusting heat distribution in the biscuit

The biscuit is then reheated to the maximum permissible temperature (e. g. same temperature as specified for heating billet 35). The heated biscuit is then transferred to the blocking die. Immediately upon removal

from the oven for the blocking operation, the biscuit will have the maximum permissible temperature in its peripheral area, and the area immediately beneath its flat upper face, and the heart of the biscuit will have a minimum temperature which may be 200° F. or more below such maximum temperature. This condition is desirable, but I find it advantageous to accentuate the temperature differential so as to confine the higher temperature more fully to the peripheral region of the biscuit. This is effected by spot-cooling the center of the biscuit on the upper face that has been fully exposed to the furnace atmosphere, as by directing a steam jet against the center of such upper face. This tends to equalize the temperature of the central area of the upper face with that of the internal heart region and that of the lower face that has been partially shielded from maximum furnace temperature by its contact with the floor of the furnace. The biscuit thus acquires, generally, a higher temperature in a zone that is confined to its peripheral region, and a temperature, several hundred degrees lower in the remaining radially inward central body (core) of the biscuit. This distribution of differential temperatures is very helpful in attaining the full results of the invention. The spot cooling operation may be performed on the biscuit as it lies under the drop hammer prior to starting the forging operation.

Blocking operation

In preparation for the blocking operation, the die blocks are cleaned by a steam blast to remove scale particles, and are then swabbed with a lubricant (e. g. emulsion type) to minimize seizing of the work by the die. The hot plastic biscuit, if not already centered in the lower die 14a of Fig. 7, is adjusted to a position as accurately centered therein as the eye of the operator can determine, and the hammer is then promptly operated to cause the upper die 16a to strike several blows in succession, driving the work blank successively deeper into the female die 14a. The hotter peripheral portion of the biscuit 36, which in plan has an area corresponding roughly to the annular area collectively defined by the inclined bottom faces 25 of the vane chambers 19, will initially flow more freely than the cooler central body of the biscuit, and will extrude simultaneously toward bottom faces 26 and 25 of the vane chambers and toward the flash zone 33 surrounding the periphery of the die cavity. The diameter of the blank will expand rapidly, and in one or two blows of the hammer, the flash 33, with its ribs 34, will be developed. Because of its thinness and the relatively low temperature of the opposed peripheral die faces 31, 31' between which it is formed, the flash will immediately harden, while the thicker body of the impeller disc 11a lying between the flash 33 and the cooler and less plastic core of the blank, will remain relatively plastic. Succeeding blows of the hammer will then drive this annular plastic body successively deeper into the vane cavities toward bottom faces 26, 25, with the flow toward faces 25 tending to be somewhat freer because of the concentration of higher temperature toward the periphery of the blank, and the blocking of the peripheral area by flash 33, and the greater resistance to flow offered by the cooler core. Thus flow is directed toward the area (bottoms 25) which is basically the most difficult area in which to attain complete filling of the vane chambers.

This is illustrated in Fig. 7, which shows the approximate marginal contour of the partially formed vanes after several blocking blows have been struck, the biscuit has been expanded to the full diameter of the die cavity, the flash 33 has developed and hardened so as to substantially close the periphery of the die against further extrusion from the die cavity, the internal pressure in the work blank, under each succeeding blow, has built up to increasingly higher values, and, with the higher flow resistance of the cooler core (labelled "precooled

core"), maximum flow (as indicated by the heavier arrows) has been developed in the region of maximum temperature, labelled "max. temp. and flow region."

Preferably, such maximum flow is expedited in the blocking operation, as in the finishing operation (as hereinafter described) by providing for the escape of gas pressure through vents 28a, 29a, etc., although I find that satisfactory results can be achieved in the over-all process without using any vents in the blocking die apart from the peripheral aperture between lip 17a and the shoulder of the die cavity at the ends of walls 15a; and the invention in its broader aspects is not restricted to the use of vents 28a, 29a, etc. This is possible because the final marginal contours of the vanes 12 are not attained in the blocking operation, enough space being left unfilled by work metal in the vane chambers to contain the trapped and compressed gas without developing back pressures so high as to increase to an impossibly high value the flow resistance developed by frictional drag of the hardening extremities of the partially formed vanes, against the heat-absorbing walls of the vane chambers. In this connection, it is to be understood that such vane extremities will be cooled by die contact, and will harden substantially as soon as the flash 33, but will be pushed ahead of the softer metal in the high temperature zone, as the pressure builds up in the latter, and will be successively driven deeper into the vane chambers, with a "cold flow" coining action which adds work hardening to these edge portions of the developing vanes, imparting maximum strength thereto.

And the larger chambers, such as hub chamber 21, are fully or substantially closed so that gas pressures will build up to much higher values in the closed spaces established therein by the advancing work blank, and such gas pressure resists the final seating of these larger portions of the impeller in the larger die chambers, and subjects the plastic body of metal to high pressure which is transmitted to the areas where the vanes 12 are being extruded into the relatively deep, narrow chambers 19, with relatively no gas pressure resisting such extrusion. Thus the thin terminal portions of the work blank are induced to fill their respective die chambers ahead of the larger central portions of the work blank.

Where it becomes necessary, the partially blocked work blank is removed from the die, reheated, again spot-cooled, reinserted in the die and subjected to further block forging until sufficiently developed for transfer to the finished die.

Preparation for finish forging

Before again reheating the work for forging in the finish die, it is descaled (as by a sand-blasting operation); is then acid-pickled to disclose surface indications, ("stringers," "laps," or other faults) that may have been developed in the previous operations; is then baked to eliminate traces of the acid, is then subjected to the "Zyglo" process in which a fluorescent penetrant is used in a bath in which the work is immersed; and is then refinished by a grinding operation to eliminate all surface indications. The blocked work blank is then reheated, (at a faster rate than in previous heating steps, so as to avoid burning off the vanes), to the maximum permissible temperature (about 2100° for high density alloy steel) and is then transferred to the finishing die, which has been prepared by steam cleaning and lubricating its surfaces.

Finish forging operation

Prior to operating the finishing hammer, the blank is spot cooled the same as previously, thus attaining substantially the same differential heat distribution as before. Under good conditions, the blank will have a core temperature of 1800°-1900° and a peripheral temperature of 2100° or somewhat higher. The spot-cooling operation preferably follows the fitting of the work

blank into the die cavity 14, with the partially formed vanes projecting into the vane chambers 19. The fitting and spot cooling operations having been performed, the operator immediately commences the operation of the drop hammer, the male die 16 quickly pounding the blank into the female die cavity until the lip 17 enters the cavity to close the die on each impact. Flow distribution will be much the same as that illustrated in Fig. 7, the cooler core being more resistant per se than the hotter peripheral region, and consequently the peripheral extremities of the blank will quickly meet the undercut or hooked end walls 22, will quickly cool by conduction into the cooler outer area of the die, and will interlock with walls 22 to resist flow over the shoulder of peripheral wall 15 of the die. Even higher pressures than in the blocking die will now be developed, in the work, and maximum inducement to flow to the bottom walls 25 and 26, and to the remote crevices 23 and 24, will be developed.

At this stage, the relieving of the pressure of trapped gas, generated by the action of the hot work metal on the lubricant in the die cavity, becomes an essential aspect of the process. Vents 28, 29, 30 will allow the escape of gas with sufficient rapidity so that no undesirable pressure will develop. Under the pressure that is developed in the body of the work blank as the die closes, the metal will flow into chambers 19 as indicated by the arrows in Fig. 9 and the vanes will be pushed into full contact with the bottom walls 25, 26, completing the marginal contours of the vanes to uniform accuracy. This entails bottoming of the vanes against bottom walls 25, 26 with considerable pressure, and thus creates the problem of avoiding the extrusion of flash whiskers into vents 28, 29, 30.

Control of vent area

The problem of regulating the vent area has been solved with the discovery that by swabbing the die surfaces with a common salt brine, a hard, pressure resistant coating is deposited on the walls of vents 28, 29, etc., the thickness of which can be regulated by the extent of swabbing. Against the heated surfaces of the die, the brine rapidly evaporates into a solid salt crust.

After four or five blanks have been processed in a die, the salt coating is renewed by again swabbing the die with brine.

After the completion of the forging operation, the impeller is removed from the die, a crowbar being inserted under the narrow flash margin 33a and prying pressure being applied, while the work is still hot, to deform the interlocked ends of the vanes sufficiently to force them past the overhanging walls 22.

The ends of the vanes are then ground off to accurate radial length, and any necessary grinding to touch up other surfaces (such as the removal of flash 33a) is performed.

In both blocking and finishing operations, the dies are mounted in standard forging presses for impact operation as contrasted to squeeze operation. As shown in Fig. 1, the female die block 15 may be mounted as the lower die member (e. g. secured to the bed of the press) and the male die block 14 may be the upper die member, mounted on the ram of the press. This facilitates locating the blocked impeller blank A on the lower die block in correct registration for working it in the die.

In both blocking and finishing dies, temperature is maintained in the range between about 400° F. and 800° F. At the start of a run, a die may begin at a temperature of about 400°, as the result of steam cleaning preparations, and may, in a steady run, approach 800° as it is heated by successive blanks of hot metal worked therein. Higher temperatures are restrained by the steam cleaning operation which is performed on each die after each successive blocking or finishing operation, to remove scale, the residue of carbonized lubricant, and such dust, and

other foreign particles as may settle on the die from the atmosphere.

MODIFIED METHOD

Fig. 10 illustrates a possible modification of the method wherein male die 16b may be fixedly mounted on the bed of the hammer, and female die 14b is mounted on the ram for striking the blows against the work. In this case, lug cavities 40 are formed in male die 16b, and corresponding lugs are formed on the back of the work, for relocating the work blank as it is removed from and reset in the hammer, and transferred from blocking die to finishing die. When the work is completed, the lugs are ground off.

I claim:

1. In the art of forging an article of high density alloy metal and of intricate, thin-walled cross-section in a die cavity having a relatively unrestricted central chamber and a plurality of outward chambers of relatively narrow, deep cross-section extending radially outwardly from said central chamber, an improved method of controlling flow of hot, plastic work metal to remote crevices of said outward chambers, including the following steps: preforming a work blank having generally the proportions of the cavity, but smaller radius than the cavity; heating said blank to a temperature near a permissible maximum to attain maximum plasticity in the peripheral region of the blank intended to fill said outward chambers; spot cooling the central area of the blank to a temperature substantially lower than that of said peripheral region, whereby to increase the flow resistance of said central area over that of said peripheral region; and hammering said blank into said cavity so as to cause said peripheral region of the blank to flow radially outwardly in said outward chambers; maintaining vents for escape of gas from said remote crevices under the pressure exerted by the advancing work metal, so as to provide for escape of gas from said remote crevices under the pressure exerted by the advancing work metal, to reduce the back pressure in said crevices so as to accelerate the work metal flow sufficiently to avoid blocking of said crevices by congealing work metal prior to attainment of full definition of the size of said vents so as to regulate surface contour in the work metal conforming to said crevices; and utilizing salt coatings on the walls of said vents for controlling said escape so as to maintain sufficient back pressure to arrest the metal flow at the point of arrival at the remote walls of said crevices.

2. An improved method of forging an article of high density alloy metal and of intricate, thin walled cross section in a finishing die cavity having a relatively unrestricted central chamber and a plurality of outward chambers of relative narrow, deep cross-section extending radially outwardly from said central chamber, including the following steps: block forging a work blank having approximately the shape and proportions of the finished article, but lacking the full depth of the narrow, deep portions thereof; reheating the blank to a temperature near a permissible maximum to obtain maximum plasticity in the peripheral region of the blank; spot cooling the central area of the blank to a temperature substantially lower than that of said peripheral region, whereby to increase the flow resistance of said central area over that of said peripheral region; hammering said blank into said cavity so as to cause said peripheral region of the blank to flow radially outwardly in said outward chambers; maintaining vents for escape of gas from said remote crevices under the pressure exerted by the advancing work metal, so as to provide for escape of gas from the remote crevices of said outward chambers under the pressure exerted by the advancing work metal, to reduce the back pressure in said crevices so as to accelerate the work metal flow sufficiently to avoid blocking of said crevices by congealing work metal prior to attainment of full definition of surface contour in the work metal conforming to said crevices; and utilizing salt coatings on the walls of said vents for controlling said escape so as to maintain sufficient back

pressure to arrest the metal flow exactly at the point of arrival at the remote walls of said crevices.

3. A method of finish-forging an impeller of high density alloy steel having a relatively large hub portion and relatively thin, deep vanes in the peripheral region thereof, comprising: forming a biscuit of work metal having a diameter somewhat less than the diameter of the impeller; heating said biscuit to a maximum permissible temperature; spot cooling the center of the heated biscuit to a temperature several hundred degrees less than the temperature of the peripheral region of said biscuit; block-forging the biscuit into a work blank having approximately the proportions and contours of the specified impeller, but with the depth dimensions of the vanes being short of the prescribed depth for the finished vanes; reheating said work blank to a temperature near a permissible maximum to obtain maximum plasticity in the peripheral region of the blank; spot cooling the central area of the blank to a temperature substantially lower than that of said peripheral region, whereby to increase the flow resistance of said central area over that of said peripheral region; hammering said blank into said cavity so as to cause said peripheral region of the blank to flow radially outwardly in said outward chambers; maintaining vents for escape of gas from said remote crevices under the pressure exerted by the advancing work metal, so as to provide for escape of gas from the remote crevices of said outward chambers under the pressure exerted by the advancing work metal, to reduce the back pressure in said crevices so as to accelerate the work metal flow sufficiently to avoid blocking of said crevices by congealing work metal prior to attainment of full definition of surface contour in the work metal.

4. A method of finish-forging an impeller of high density alloy steel having a relatively large hub portion and relatively thin, deep vanes in the peripheral region thereof, comprising: forming a biscuit of work metal having a diameter somewhat less than the diameter of the impeller; heating said biscuit to a maximum permissible temperature; spot cooling the center of the heated biscuit to a temperature several hundred degrees less than the temperature of the peripheral region of said biscuit; block-forging the biscuit in a blocking die having a flash apron provided with concentric grooves beginning just beyond the periphery of the die cavity and hammering the heated biscuit into the die cavity and expanding it radially to form a blank while extruding flash from the periphery of the cavity and into said grooves to provide concentric locking beads on said flash, in interlocking coupling with said grooves, for restraining further radial expansion of the work blank; removing the blank from the blocking die, reheating it and transferring it to a finishing die having vane chambers provided with reverse, overhanging draft walls at their outer ends; and hammering the reheated work blank into the die cavity with the ends of the vanes interlocking with said draft walls to resist radial extrusion thereof from the periphery of the die.

5. The method defined in claim 4, including the step of providing for escape of gas from the remote crevices of said vane chambers to reduce back pressure therein, thereby promoting the movement of work metal into said remote crevices.

6. The method defined in claim 5 wherein vents, in the form of a restricted port at each of said remote crevices, are utilized for said escape of gas pressure, and including the further step of regulating the area of said vents to avoid the formation of flash whiskers therein.

7. The method defined in claim 6, including the step of periodically applying a salt solution to said vents as the means for regulating the area thereof.

8. The method defined in the claim 4, including the steps of forcibly removing the forged impeller from the finishing die cavity, and thereafter grinding off the ends of the vanes.

9. An improved method of forging an article of high

density alloy steel having a plurality of deep, thin vanes radiating from a hub and extending axially from a relatively thick body disc in the form of a radial flange on said hub, said vanes, hub and disc being integrally joined to one another, said method comprising the following steps: fabricating a biscuit of said metal having greater axial depth and smaller diameter than the finished article; heating said biscuit to a forging temperature; subjecting said heated biscuit to a block-forging operation wherein the heated metal of the biscuit is extruded radially outwardly from the center of the biscuit to form an intermediate work blank having nascent vanes of approximately the shape and proportions of the finished article but lacking the full depth of the vanes thereof; reheating said intermediate blank to a temperature near a permissible maximum to attain maximum plasticity in the peripheral region of the blank; spot-cooling the hub area of the blank to a temperature such as to render said hub area substantially less plastic and more flow-resistant than said peripheral region; placing the reheated and spot-cooled blank on a die having a die cavity with a relatively unrestricted central hub-forming chamber and a plurality of outward chambers of relatively deep, narrow cross-section radiating from said central chamber, with said nascent vanes projecting into said outward chambers; hammering said blank into said die cavity so as to cause said nascent vanes to be thinned and extruded axially into said outward chambers to fill the same and impart the full contours of the die cavity to the work blank; and providing for escape of gas from the extremities of said outward chambers remote from said central chamber, so as to accelerate the work flow sufficiently to avoid blocking of said extremities by congealing work metal prior to attainment of full definition of the contours of said article in the work metal, while restricting such escape so as to maintain sufficient back pressure to arrest the metal flow at the point of arrival of the work metal at said extremities of the outward chambers.

10. An improved method of forging an article of high density alloy steel having a plurality of deep, thin vanes radiating from a hub and extending axially from a relatively thick body disc in the form of a radial flange on said hub, said vanes, hub and disc being integrally joined to one another, said method comprising the following steps: heating to a plastic state a generally cylindrical billet of said metal having a diameter less than two thirds that of the finished article and an axial dimension correspondingly greater than that of the finished article; up-

setting said billet endwise to form a biscuit having a diameter not more than two thirds the diameter of the finished article and of greater axial dimension; reheating said biscuit to a state of maximum plasticity short of the point of damaging the biscuit; spot cooling the center of the biscuit to a temperature several hundred degrees less than the peripheral temperature of the biscuit to reduce its plasticity while maintaining maximum plasticity in the peripheral area of the biscuit; subjecting said reheated biscuit to a block-forging operation wherein the heated metal of the biscuit is extruded radially outwardly from the center of the biscuit to form an intermediate work blank having nascent vanes of approximately the shape and proportions of the finished article but lacking the full depth of the vanes thereof; reheating said intermediate blank to a temperature near a permissible maximum to attain maximum plasticity in the peripheral region of the blank; spot-cooling the hub area of the blank to render said hub area substantially less plastic and more flow-resistant than said peripheral region; placing the reheated and spot-cooled blank on a die having a die cavity with a relatively unrestricted central hub-forming chamber and a plurality of outward chambers of relatively deep, narrow cross-section radiating from said central chamber, with said nascent vanes projecting into said outward chambers; hammering said blank into said die cavity so as to cause said nascent vanes to be thinned and extruded axially into said outward chambers to fill the same and impart the full contours of the die cavity to the work blank; and providing for escape of gas from the extremities of said outward chambers remote from said central chamber, so as to accelerate the work flow sufficiently to avoid blocking of said extremities by congealing work metal prior to attainment of full definition of the contours of said article in the work metal, while restricting such escape so as to maintain sufficient back pressure to arrest the metal flow at the point of arrival of the work metal at said extremities of the outward chambers.

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