Feb. 15, 1944. W. E. JOHN 2,341,784

METHOD OF PRODUCING FILLETS IN HOLLOW STEEL PROPELLER BLADES

Filed Dec. 18, 1941 2 Sheets-Sheet 1

Fig. 1

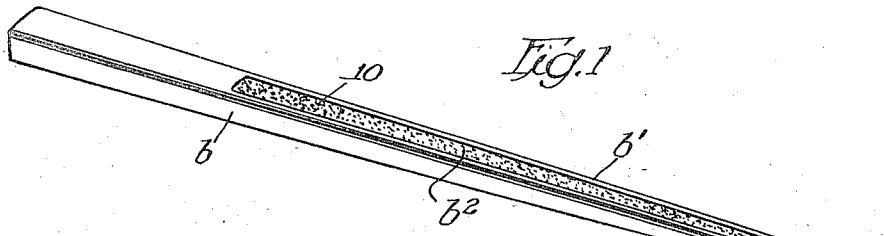


Fig. 2

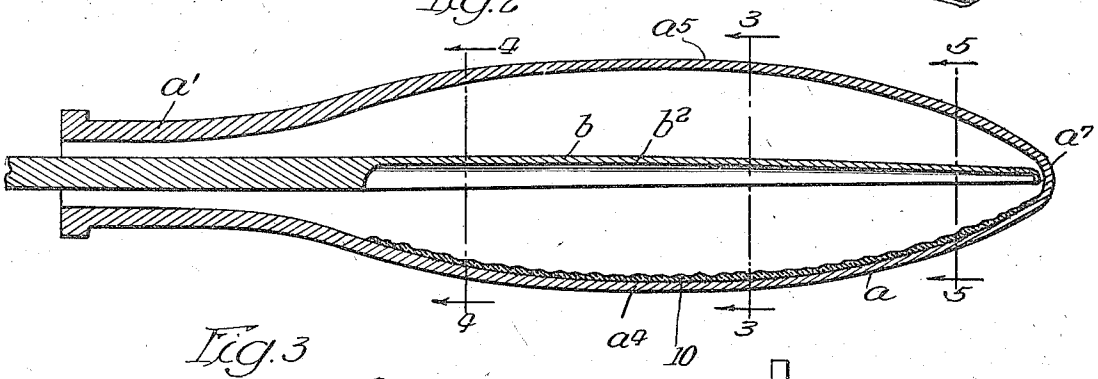


Fig. 3

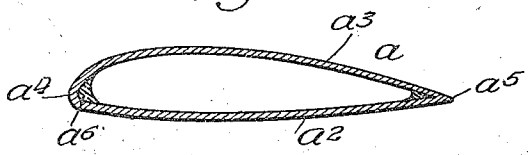


Fig. 4

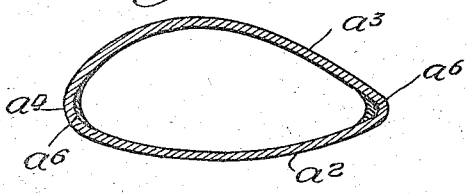


Fig. 5

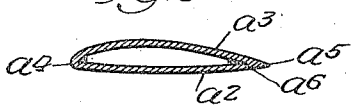


Fig. 6

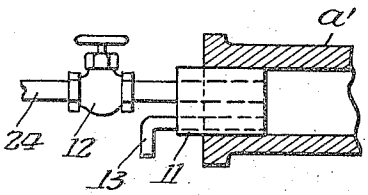
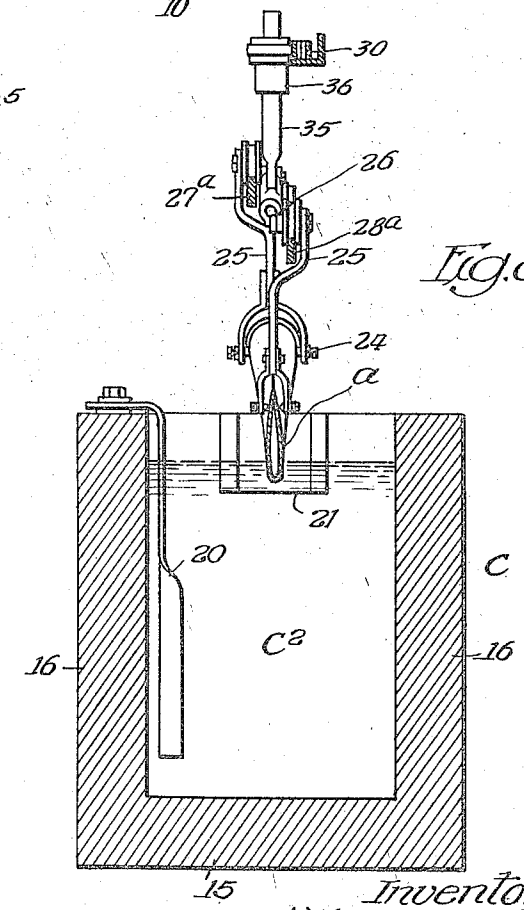


Fig. 8



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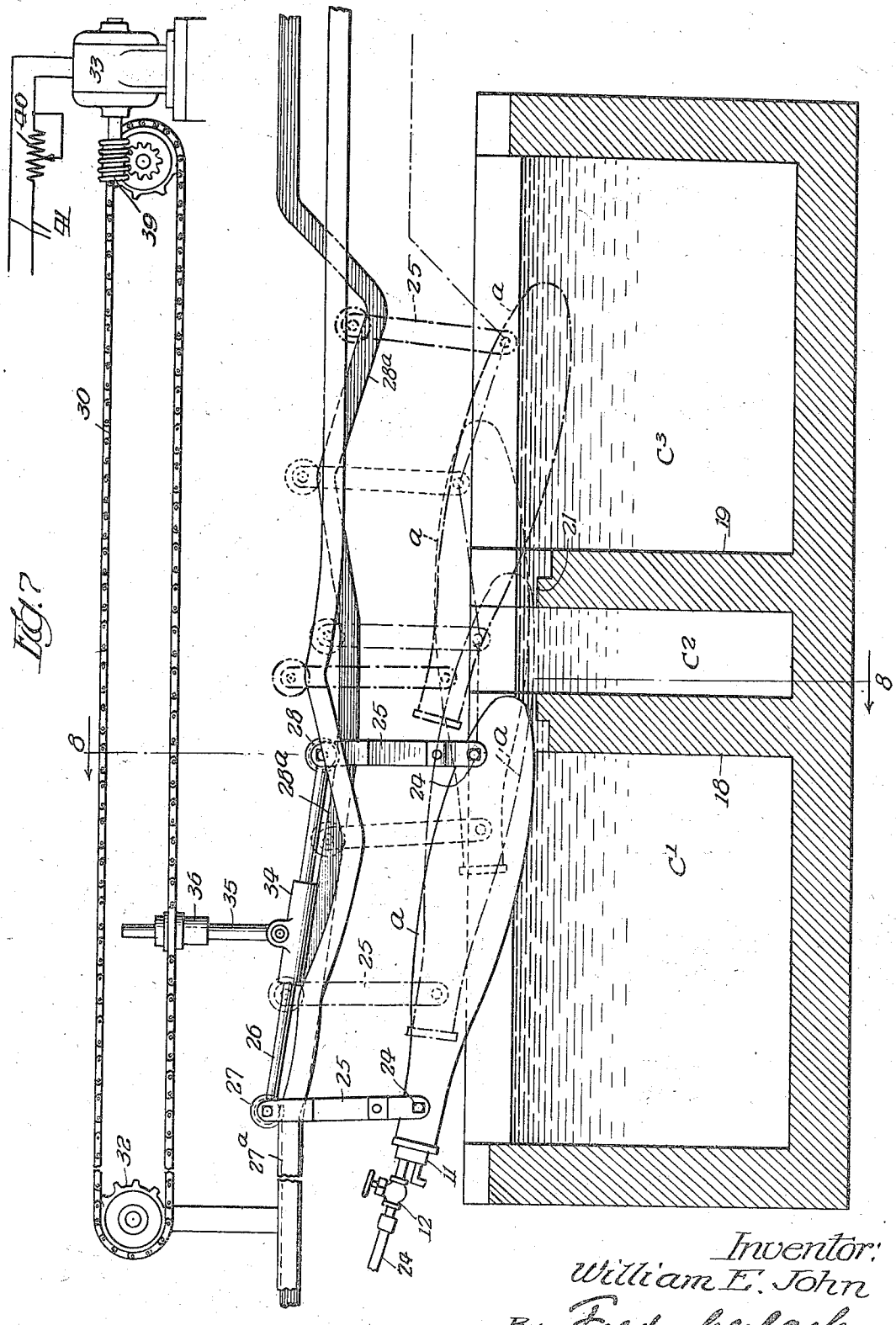

Fig. 7

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UNITED STATES PATENT OFFICE

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METHOD OF PRODUCING FILLETS IN HOLLOW STEEL PROPELLER BLADES

William E. John, Williamsport, Pa., assignor to The Aviation Corporation, New York, N. Y.

Application December 18, 1941, Serial No. 423,441

9 Claims. (Cl. 22—204)

The invention relates to the fabrication of hollow steel propeller blades.

In propeller blades for aircraft formed either from tubular blanks or plates welded together, and in which the working portions of the blade are of airfoil cross section, the sharp or rounded interior corners at the meeting of the two faces which form the leading and trailing edges of the blade increase the stresses at these locations which are apt to exceed the endurance limit of the steel from which the blade is fabricated, and result in fatigue failure. The design loads of the blade make the sections at the edges critical and the working or breathing of the face sections while in service result in transverse or peripheral loads in addition to the primary radial loads which accentuate the possibility of fatigue failures. For the purpose of reducing the increase of stresses at these corners, fillets of suitable metal fused to the steel have been found to be beneficial around the inner corners along the edges of the blade. The beneficial effect of such fillets depends mainly on their form rather than on the physical properties of the material from which they are made and the modulus of elasticity of the fillet metal must be approximately the same as the steel of the blade. Fillets of this character are produced by melting a suitable alloy in the inside angular corner between the sides of the blade after it has been shaped to airfoil contour, by melting and capillary action. The formation of the fillet is a function of the angle at the meeting corners of the inside faces, which varies at different radial stations of the blade. The ability of the melted metal to flow and form the fillet increases as the angle of the corner decreases. The size of the fillet may be governed, within limits, by the amount of the fillet-material that is melted in the regions of varying angles between the faces. The formation of such fillets in propeller blades for maximum efficiency presents difficult problems because of the curvature of the blade plan forms, the twist in the blade, the formation of the fillet of desired size in the varying angles in the inside corners of the blade, and the tendency of the molten metal to run to the lowest point in the chamber in the blank and overcome by gravity the capillarity, regardless of the position in which the blade is supported. Another difficulty results from the use of brass alloys of relatively high melting point to produce the desired physical properties in the fillet. When the blades are heated to a temperature considerably above the critical temperature of the steel used in quenching for hardening, a coarse grain structure is produced in the steel which tends to set up cracks in the blade when cooled.

One object of the invention is to provide an improved method by which fillets will be uniformly produced in the interior corners between the face-sections of hollow steel propeller blades so that they will be of the desired or predetermined form along the interior corners between the blade faces.

Another object of the invention is to provide a method of fabricating hollow steel propeller blades with fillets in which the temperature necessary to melt the fillet-material is controlled so it will not be substantially higher than the critical temperature of the steel used for hardening so as to avoid producing a coarse grain structure in the steel or setting up cracks in the blade when it is cooled.

A still further object of the invention is to provide a method by which the fillet-material will be deposited and distributed in the blade substantially in accordance with the form desired at different radial stations and melted when it is deposited along the meeting corners of the inner faces of the face-sections.

Another object of the invention is to provide an improved method of producing fillets in hollow steel propeller blades, in which the edge portion of the blade is immersed in a bath, the temperature of which can be controlled within desired limits, for melting the fillet-forming material and fusing it to the steel in the blade.

Another object of the invention is to provide an improved method of producing fillets in hollow steel propeller blades in which non-oxidizing gas to which the fillet-material is subjected is confined to the interior of the blade during the formation of the fillets in the blade.

A further object of the invention is to provide a method of forming fillets in hollow steel propeller blades in which the edge-portions of the blade are successively immersed in a bath for heating it to near melting point of the fillet-material, to melting temperature, and to cooling temperature without displacement of the fillet-material, such as a powder, deposited in the corner.

Other objects of the invention will appear from the detailed description.

The invention consists in the several novel features hereinafter set forth and more particularly defined by claims at the conclusion hereof.

In the drawings, Fig. 1 is a perspective of the measuring tool used for depositing the brass alloy

in powder form into the interior corner of the hollow blade for the formation of an internal fillet. Fig. 2 is a longitudinal section of the hollow propeller blade with the charge of the fillet-material deposited into the inner corner along one of the edges of the blade. Fig. 3 is a section taken on line 3—3 of Fig. 2, Fig. 4 is a section taken on line 4—4 of Fig. 2, and Fig. 5 is a section on line 5—5 of Fig. 2 after the fillet has been formed in the blade. Fig. 6 is a section showing the plug used for closing and supplying non-oxidizing gas to the chamber in the blade during the melting of the fillet-material. Fig. 7 is a longitudinal section of apparatus used in forming the fillet in the blade. Fig. 8 is a section taken on line 8—8 of Fig. 7.

The invention is exemplified for forming fillets in a hollow steel propeller blade *a*. Before the fillets are formed the blade is shaped to form a shank a^1 which is adapted to be secured in a propeller hub and usually circular in cross-section, a working portion of airfoil cross-section with a camber member or pressure face a^2, a camber member or suction face a^3, a curved leading edge a^4 and a relatively sharp trailing edge a^5 and a tip a^7. In plan form the leading and trailing edges are longitudinally curved and terminate in a curved closed tip. In some instances the edges are slightly twisted or helical. The curved or angular interior corners a^6 between the camber members along the leading edge and the relatively sharp angular interior corners between said members along the trailing edge are the places where fillets are desired for reducing stress-raising effects and of the size and form for effecting the desired increase of the endurance limit and overcoming fatigue failures.

In carrying out the improved method a measuring tool *b* is used to deposit the fillet-forming material, which is fluent, such as powder, into one of the interior corners and longitudinally throughout the length of one of the edges of the blade in which the fillet is to be fused. The tool consists of a tapered bar b^1 provided with a longitudinally extending pocket channel b^2 adapted to retain a charge of fillet-forming material 10. The channel is tapered longitudinally to retain the powder 10 in quantities proportionate to the size of the fillet desired at different radial stations of the blade. The shank portion of the blade, which is circular in cross section, is gradually blended into the widest portion of the camber sections and the latter are tapered from the widest portion to the tip. The channel or pocket b^2 is designed to distribute the powder 10 along each interior corner of the blade in accordance with the form desired at the different radial stations and in accordance with the angular variations in the interior corners. The tool *b*, after it has been loaded with the brazing material, is passed through the bore of the shank into the chamber in the blade until it engages, and is longitudinally positioned by, the closed tip. The tool is then turned to invert the pocket b^2 so that the powder 10 will be deposited into the interior corner along one edge of the blade as illustrated in Fig. 2. The blade is supported edgewise while the powder 10 is deposited therein and retained in such position during the subsequent fusing operation. The hollow blade is fabricated to substantially its finished shape, in accordance with any suitable method, before the powder is inserted for the forming of the fillets. As an example of the fillet-material, an alloy of copper 60 percent, nickel 3 percent, zinc 36 percent, and tin 1 percent is used which will melt at a temperature slightly higher than, for example 1650° F., the highest temperature required in the subsequent heat treating of the blank. For example, if the temperature used in subsequent heat treating of the blade for hardening is 1650° F., the alloy selected for the fillet forming material will have a melting point of about 1700° F.

Next, the bore of the shank of the blade is closed by a plug 11 which is sweated or brazed into the shank. The plug is provided with an inlet pipe 11^a for the introduction of a non-oxidizing gas into the blade, a valve 12, for controlling the delivery of gas into the chamber in the blade, and an outlet pipe 13. A non-oxidizing gas is used so that subsequent heating operations will not cause oxidizing and scaling of the inside portions of the blade. The supply of gas is regulated by valve 12. By closing the blank, only the inside of the blade is treated with gas, while the melting of the fillet-material is effected by heat applied from the outside to the edge of the blade.

Next the blade with the fillet-material therein is pre-heated or soaked to a temperature between 1000° and 1200° F. in a suitable furnace. The temperature of the entire blade is uniformly raised to the pre-heated temperature so that no local strains due to the heating will be imparted to the blade. This pre-heat temperature is lower than that required for fusing the metallic fillet-forming material, and prepares the blade for expediting the subsequent melting of the fillet-material.

Next the fillet-forming material is fused into the interior corners of the blade by apparatus which applies localized heat progressively to the inner corner of the blade along the edge which contains the fillet-material while the blade is suspended and passed through a bath. An example of the apparatus usable for this purpose is shown in Figs. 7 and 8. This apparatus comprises a suitable tank *c* provided with an open top, bottom 15, sides 16, ends 17, and transverse partitions 18 and 19 which divide the chamber in the structure into three compartments c^1, c^2 and c^3. The walls of the structure are made of suitable ceramic or refractory material. The compartments are adapted to contain a suitable bath, such as molten salt, for heating an edge portion of the blade immersed therein. Each compartment is provided with a pair of electrodes 20 to which electric current is supplied of sufficient voltage and amperage to maintain the salt in each compartment at the desired temperature, as hereinafter described. The current supplied to the electrodes for each of the compartments is controlled by suitable devices so that the bath in the three compartments may be kept at different temperatures. The partitions 18 and 19 are provided with openings 21 in their upper margins approximately of sufficient size to permit the greatest cross-section of the blade to move longitudinally, and to permit one edge of the blade, to pass through, the bath in compartment c^2. The level of the molten bath is maintained a few inches, or at a point sufficiently above the bottom of the openings 21 for immersion of one edge portion of the blade between partitions 18 and 19 for fusing the fillet-forming material in the blade between said partitions. The temperature of the bath in compartment c^1 is higher than the 1200° F. pre-heat temperature of the blade and slightly lower than the temperature required for fusing the fillet-forming material.

For example, if the fusion temperature of the fillet-material used is about 1700° F., the temperature in compartment c^1 may be maintained at approximately 1300° to 1500° F. The temperature of the bath compartment c^2 is maintained at a point which will melt the fillet-forming material, for example, 1700° F. The temperature of the salt in compartment c^3 is maintained at a sufficiently lower temperature, for example, 1400° F. to cool the fused fillet-material sufficiently so it will harden. As the blade is passed progressively through the three compartments of the bath, the temperature of the blade is successively elevated in the bath in compartment c^1 from pre-heat temperature to a degree approaching the fusion temperature of the fillet-forming material; in the bath in compartment c^2 to the fusing temperature of the fillet-material, and in the bath in compartment c^3 the temperature is lowered sufficiently so that the fillet is hardened. This exemplifies a method in which the temperature of the fillet-material is progressively varied and definitely controlled to raise the temperature almost to the melting point, then increased to the melting point to form the fillet, and then partially cooled so the fillet will solidify and be fused with the steel in, and fill the interior corners of, the blade.

In progressively passing the blade endwise through the bath it is desirable to maintain its edgewise position so that the fillet-forming powder will not be displaced from the point of deposit, and also to tilt the blade to immerse the longitudinally curved edge of the blade to the desired depth. For this purpose the blade is transported so its lower edge will pass through the bath in the tank *c*. The blade is secured in clamps **24** adjacent the shank and the tip, respectively, on a carriage which comprises a pair of suspension bars **25** or hangers which carry the clamps, and a link **26** which connects the hangers for simultaneous longitudinal movement and is pivoted to the upper ends of the hangers for independent vertical movement of the shank and tip portions of the blade. The carriage is provided with a rear roller **27** which travels on a stationary track **27a** and a front roller **28** which is adapted to travel on the stationary track **28a**. The tracks are irregularly shaped, as shown, to control the vertical tilting movements of the blade as it is propelled forwardly so that the edge portion adjacent the tip will be first immersed in the bath in compartment c^1, then moved longitudinally through the bath in compartment c^2, and then into and out of the bath in compartment c^3. As the blade advances, it will be tilted longitudinally by the tracks so that zones of the edge of the blade which is longitudinally curved will be progressively immersed in the bath to maintain approximately the same depth of immersion of the edge portion of the blade in which the fillet is desired. The longitudinal tilting of the blade is limited and is such that the zone of the blade-edge, while passing through the bath in compartment c^2, will be substantially horizontal so that the melted material will remain substantially in place for localized capillary action. When powdered fillet-material is used, it will not be substantially displaced from the place where it has been deposited and where the fillet is desired. The carriage is propelled by power from an electric motor **33** which is connected through suitable speed-reducing gearing **39** to drive one of the sprocket wheels **32**, around which the conveyor **30** passes. The speed of the motor is timed to move the blade through the bath at a predetermined and correct rate of travel, so that the progressive heating, melting and partial cooling will occur while the blade is immersed in the bath. The link **26**, which connects the axles of rollers **27** and **28**, is connected to the conveyor **30** by a bracket **34** which is fixed to link **26** and post **35**, the lower end of which is pivoted to bracket **34** and the upper end of which is slidable in a lug **36**. Said lug is fixed to and movable with the lower reach of the conveyor **30**. During the movement of the blade carriage, post **35** is free to slide vertically in lug **36** so that link **26** is free to move vertically and tilt. The tracks **27a** and **28a** are designed to guide the carriage and blade so the edge adjacent the tip will be first immersed, the blade will be tilted to immerse its following edge portion, and so that the zone of the edge portion immersed in the bath in compartment *c* will be nearly horizontal during the melting of the fillet-forming material to prevent it, when melted, from being dislocated, to immerse the blade in the bath in compartment c^3 for partial cooling, and then elevate the blade out of the bath when the fillet has been completed. After the completion of the fillet the blade can be removed from hangers **25** and the blade carriage can be propelled to the left tank for repeating the fillet-forming operation to produce the fillet in the other edge portion of the blade. For this purpose the motor **33** may be of the reversible type.

The duration of the treatment of the blade in transit through the bath is determined by its speed of travel and may be regulated. The motor **33** is of the variable speed type and a rheostat **40** is included in one of the conductors **41**, which supply current to the motor. By varying through this rheostat the resistance in the line which supplies current to the motor, the speed of travel of the chain **30** and the blade carriage may be varied to immerse the lower edge of the blade in the bath the optimum period for producing the fillet in the blade.

In forming the fillets in the blade, a charge of fillet-material is deposited by the tool **15** into the inner corner along one of the edges of the blade according to the size of the fillet desired at the different radial stations and according to the sharpness of the angle in the corner from the tip to the cylindrical shank portion of the blade. The valve-plug **20** is then secured in the bore of the shank end of the blade to close the chamber in the blade so it will hold gas. The entire blade is then uniformly preheated to a temperature substantially between 1000° to 1200° F. to avoid local strains in the structure of the blade during the fillet-forming. The blade is next secured in the clamps **24** on the carriage with the edge into which the fillet-material has been placed lowermost. Valve **12** is then opened to admit non-oxidizing gas from a suitable source into the chamber in the hollow blade to prevent oxidizing and scaling of the inside of the blade. This is continued during the entire fillet-forming operation. The carriage is started from the left hand end of the tank *c*. The motor **33** is then started to advance the carriage and blade endwise to the right at the correct predetermined speed to complete the formation of the fillet in one edge. During this travel of the blade the edge of the blade near the tip with the inner corner into which the fillet-material has been placed will be first immersed in the bath in chamber c^1, the temperature of which is con-

trolled to remain approximately 1500° F. so that the fillet-material and said edge portion will be heated somewhat below the melting point of the fillet-material. As the carriage continues to advance, the lower edge portion of the blade which has been immersed in compartment c^1 will pass through the bath in compartment c^2 where the temperature is controlled to remain at about 1700° F., to melt the fillet-material in the zone near the tip of the blade and cause it to fuse into the inner corner of the blade by capillary attraction and form the fillet. As the carriage advances further, the portion of the blade in which the fillet-material has been fused will pass into the bath in compartment c^3, where the temperature is controlled to remain at approximately 1400° F., which is sufficient to partially cool and solidify the fillet. During each forward stroke of the carriage the edge portion of the blade inwardly of the tip will be progressively and similarly immersed, and be heated, melted and cooled until the fillet h has been formed throughout the length of the inner corner of the blade where the fillet is desired. After the entire fillet has been formed, the tracks 27^a 28^a will guide the carriage to lift the blade out of the tank c. An important attribute of this method is that the zone of the edge of the blade wherein the fillet-forming material is melted and as it passes through the bath in compartment c^2, will be substantially horizontal so that the melted material will be retained in its place in the inner corner for capillary action. This substantial horizontality during the melting is maintained throughout the longitudinally curved inner corner of the blade where the fillet is desired. After the fillet has been completed in the interior corner of one edge of the blade, the blade will be disconnected from the carriage, plug 11 will be removed, and the same cycle of steps will then be carried out with fillet-material in the inner corner along the opposite edge of the blade to form the fillet in that corner. After the fillet has been formed in both of the inner corners along the leading and trailing edges the blade will be hardened by quenching at a temperature of approximately 1650° F.

The invention exemplifies a method by which fillets are formed in the blade which is first shaped to provide a working portion of airfoil contour longitudinally curved leading and trailing edges, a closed tip and a shank; by which the entire blade is pre-heated to avoid setting up internal strains during the forming of the fillet; by which the chamber in the blade is utilized to hold non-oxidizing gas during the formation of the fillet in a bath; by which the fillet-material may be deposited and distributed into the inner corner throughout the length of the blade in which the fillet is desired and according to the size desired at different radial stations of the blade; by which a fillet-material is melted at a controlled temperature only slightly in excess of the critical temperature of the steel to avoid producing a coarse grain structure, or tending to set up cracks in the blade when it is finally quenched for hardening after the fillet has been formed therein; by which the melting of the fillet-material is done by progressively immersing the edge portion of the blade in a bath, the temperature of which can be controlled; by which the fillet-material in a longitudinally curved edge portion of the blade is melted while it is substantially horizontal so that the melted metal will remain in place and join to the steel by capillary action; by which the edge portions of the blade are progressively immersed in a bath and the temperature successively raised to a point approaching the melting point, then to the melting point, and then lowered to cool and solidify the fillet; by which the fillet-forming steps can be expeditiously carried on and controlled to produce uniform fillets in the blades; and by which the fillets of the desired size will be formed throughout the desired extent of the inner corners of the blade.

The invention is not to be understood as restricted to the details set forth, since these may be modified within the scope of the appended claims without departing from the spirit and scope of the invention.

What I regard as new and desire to claim by Letters Patent is:

1. That improvement in forming a fillet in a hollow steel propeller blade having a working portion of airfoil cross section and leading and trailing edges, which comprises uniformly heating the entire blade to a temperature below the melting point of the material, placing fillet forming material in the inside corner along one edge of the blade, successively submerging the edge portion of the blade containing the material in a bath having a temperature higher than the preheat temperature and less than its melting temperature, then in a bath having a controlled melting temperature for the material and fusing it to the metal of the blade to form the fillet, and then in a bath having a cooling temperature and movably tilting the blade longitudinally so as to keep said edge portion continuously immersed in and between the baths.

2. That improvement in forming a fillet in a hollow steel propeller blade comprising a working portion of airfoil cross section and leading and trailing edges, one of which is longitudinally curved, which comprises placing fillet-forming material in the inside corner along the longitudinally curved edge of the blade, progressively immersing a zone of the edge portion in a bath of sufficient temperature to melt the material and fuse it with the metal of the blade, and automatically tilting the blade during its progression to maintain substantial horizontality of the zone in which the material is being melted and to maintain said edge portion continuously immersed in and between said baths.

3. That improvement in forming a fillet in a hollow steel propeller blade having a working portion of airfoil cross section and longitudinally curved leading and trailing edges, which comprises placing fillet-forming material in the inside corner along one edge of the blade, progressively immersing and passing the portions of said edge endwise through a bath of a temperature somewhat below the melting point of the material, then through a bath of sufficient temperature to melt the material and thereby form the fillet, and then through a bath of cooling temperature continuously moving the blade at a controlled rate longitudinally, and tilting the blade vertically in a predetermined path so that said edge portion remains continuously immersed through the baths.

4. That improvement in forming a fillet in a hollow steel propeller blade having a working portion of airfoil cross section and leading and trailing edges, which comprises placing fillet-forming material in the inside corner along one edge of the blade, immersing the edge portion around said material in a bath of sufficient and

controlled temperature to melt and fuse said material with the metal of the blade, advancing the blade longitudinally at a controlled rate and automatically tilting the blade longitudinally with said edge immersed and thereby progressively forming a continuous fillet around said inside corner.

5. That improvement in forming a fillet in a hollow steel propeller blade having a working portion of airfoil cross section and leading and trailing edges, which comprises placing fillet-forming material in the inside corner along one edge of the blade, successively immersing the edge portion containing said material in a bath having a temperature somewhat below the melting temperature of said material and then in a bath having a controlled melting temperature for fusing said material with the metal in the blade by progressively advancing the blade longitudinally at a controlled rate while it is immersed in and between said baths and thereby forming a continuous fillet along said inside corner.

6. That improvement in forming a fillet in a hollow steel propeller blade having a working portion of airfoil cross section and leading and trailing edges, which comprises placing fillet-forming material in the inside corner along one edge of the blade, successively immersing the edge portion containing said material in a bath having a temperature somewhat below the melting temperature of said material and then in a bath having a controlled melting temperature for fusing said material with the metal in the blade by progressively advancing and automatically tilting the blade longitudinally with said edge continuously immersed in and between the baths and thereby forming a continuous fillet along said inside corner.

7. That improvement in forming a fillet in a hollow steel propeller blade having a working portion of airfoil cross section and leading and trailing edges, which comprises placing fillet-forming material in the inside corner along one edge of the blade, successively immersing the edge portion around said material in a bath having a controlled temperature somewhat less than the melting point of said material, then in a bath having a sufficient temperature for melting said material and fusing it with the metal of the blade and then in a bath having a cooling temperature, automatically advancing the blade longitudinally at a controlled rate with said edge continuously immersed in and between said baths and thereby forming a continuous fillet along said inside corner, said edge portion being retained continuously submerged while it is subjected to all of said temperatures.

8. That improvement in forming a fillet in a hollow steel propeller blade having a working portion of airfoil cross section and leading and trailing edges, which comprises placing fillet-forming material in the inside corner along one edge of the blade, successively immersing the edge portion around said material in a bath having a controlled temperature somewhat less than the melting point of said material, then in a bath having a sufficient temperature for melting said material and fusing it with the metal of the blade and then in a bath having a cooling temperature, advancing the blade longitudinally at a controlled rate while said edge is immersed and automatically tilting the blade longitudinally to keep said edge continuously immersed in and between said baths and thereby forming a continuous fillet along said inside corner.

9. That improvement in forming a fillet in a hollow steel propeller blade having working portions of airfoil cross section and curved leading and trailing edges, which comprises placing fillet-forming material in the inside corner along one edge of the blade, suspending the blade from above at points adjacent its ends so its lower portion throughout its length can be immersed in a bath, successively immersing the lower edge portion containing said material in a bath having a temperature somewhat below the melting temperature of said material, and then in a bath having a controlled melting temperature for fusing said material with the metal in the blade, and finally in a cooling bath by progressively advancing the blade longitudinally and automatically tilting the blade longitudinally by raising and lowering of its ends while said edge remains continuously immersed in said baths and thereby forming a continuous fillet along said inside corner.

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