United States Patent Office 2,941,281
Patented June 21, 1960

2,941,281

HOT WORKABLE, HEAT RESISTANT METAL BODIES

Harold William George Hignett, Birmingham, England, assignor to The International Nickel Company, Inc., New York, N.Y., a corporation of Delaware

No Drawing. Filed Dec. 2, 1954, Ser. No. 472,755

Claims priority, application Great Britain Dec. 4, 1953

3 Claims. (Cl. 29—182.3)

The present invention relates to a method for producing hot-worked metal articles containing inner passages or cavities and, more particularly, to a special filler material particularly adapted for the production of such hollowed-out articles.

It is known that if one or more holes are made in a metallic body and filled with an appropriate material, and the body is then hot-worked by extrusion or otherwise, the filler material will flow with the metal. If the filler can be removed by any process which does not affect the metal, the hot-worked body or sections cut from it will still contain holes after the removal of the filler, but the size and shape of these will depend on the change which has taken place in the external dimensions of the body and on the nature of the filler. Assuming that the filler behaves in exactly the same way as the metal itself when subjected to deformation, it is possible to elongate the holes and reduce them in cross-sectional area without changing their cross-sectional shape. This can be done, for instance, by extruding a billet or the like having a filled hole or holes extending parallel to the axis without changing the cross-sectional shape of the billet. If the cross-sectional shape of the billet or the like is changed, e.g. by hot-rolling or forging between dies, the cross-sectional shape of the filled holes will be changed in a way depending on the forces acting in the particular region of the billet or the like where they lie. In practice, when an axial hole has been made by removing a rod of metal, it is rare for the filler inserted in the hole to behave just as that rod would have done, and the extent to which the final cross-sectional shape of the hole resembles the cross-sectional shape which the rod of metal would have had depends on hot-working characteristics of the filler material.

By extrusion of the filled billet or the like through a die of a different shape and smaller cross-sectional area than the billet or the like an elongated body can be produced in which the holes are elongated, reduced in cross-sectional area, and also changed in shape.

If the size, shape and distribution of the final holes are to be uniform throughout a substantial proportion of the length of such an extruded product, it is essential that the extrusion be carried out under conditions of external lubrication and degree of reduction such that regular flow of the billet or the like occurs. By "regular flow" I mean flow such that the relative distribution of metal is the same in the extruded product as in the filled billet or the like.

Provided that regular flow is achieved, the final shape of the holes left after removing the filler material from an extruded billet will thus depend on:

(*a*) The hot-working properties of filler and billet;

(*b*) The original shape of the holes;

(*c*) The positions of the holes in the billet cross-section; and

(*d*) The change in cross-sectional shape of the billet on extrusion.

It has now been discovered that when a special filler material having a deformability bearing a critical relationship under the conditions of the hot working to that of the metal or alloy concerned is employed in the manufacture of hot-worked metal articles containing internal passages or cavities, improved results are obtained and it is possible to produce such hot-worked metal articles containing internal passages or cavities at controllably-disposed locations therein, said passages or cavities being of readily-controllable cross-section and having smooth walls.

It is an object of the present invention to provide an improved filler material specially adapted for the production of hot-worked metal articles containing controllably-disposed internal passages or cavities.

It is a further object of the present invention to provide a method of making an improved filler material specially adapted for the production of hot-worked metal articles containing controllably-disposed internal passages or cavities.

It is a further object of the present invention to provide an improved method for manufacturing hot-worked metal articles containing controllably-disposed and controllably-dimensioned internal passages or cavities.

It is yet a further object of the present invention to provide an improved method for manufacturing extruded metal articles containing controllably-disposed and controllably-dimensioned internal passages or cavities.

Another object of the invention is to provide a filler material which can be employed to define holes or other internal cavities or passages in metal shapes while said shapes are being subjected to hot working operations but which can readily be removed from the completed hot-worked article to provide internal cavities or passages having smooth walls.

To exercise the closest control over the form and dimensions of the holes in the finished article made by hot-working a metal body containing one or more holes filled with filler material, it is essential that the filler should have a resistance to deformation that is as close as possible to that of the metal, since otherwise the lines of the flow of the filler will not follow those of the surrounding metal. Thus in the extrusion of a billet having filled holes disposed parallel to its axis and to the direction of extrusion, if the filler is more readily deformable than the metal, not only will the reduction in the cross-sectional area of a filled hole be proportionately greater than that of the metal, but also this area will vary along the length of the hole. The extent of these variations, measured for example as the mean deviation from the mean cross-sectional area, will increase with the deformability of the filler.

If the filler is less readily deformable than the metal, it will tend to act as a mandrel in the extrusion. The filler will all pass through the die before extrusion of the metal is complete and the trailing end of the extruded section will contain no filler. Further, the cross-sectional area of the hole formed will be irregular.

I have found that a quantity I call the "deformability factor" must lie within certain limits for success. This factor is determined by reducing the area, by extrusion or other hot-working, of metal with a filled hole under conditions ensuring regular flow and ascertaining the reduction of the cross-sectional area of both the metal and the filler after the hot working. If the ratio of the filler area before hot working to the filler area after hot working is R.1 and the similar ratio of the metal areas is R.2, then the deformability factor is $R1/R2$. The deformability factor is thus a measure of the relative deformability of the filler and the metal under the hot working conditions. Since the deformabilities of metal and filler may vary at different rates with changing temperature this factor may depend on the temperature of hot working.

I have found that if the mean deviation from the mean cross-sectional area of the filled hole is not to be more than 5%, the deformability factor should not be greater than 1.10. If it is more than 1.20 the mean deviation will be about 10% or more. Beyond this there is a danger that very small holes will be completely closed at one or more points along their length, and in the case of extrusion the filler will tend to squirt forward within the metal into the blind front end of the billet. This part of the hole is of irregular section, and the material so lost affects the predetermined mean size of the remaining part of the hole.

To be satisfactory, therefore, the filler used must be such that the deformability factor at the hot-working temperature is fairly close to unity, and it must also be a coherent body, i.e., must have tensile as well as compressive strength. Moreover, the filler must, of course, be capable of being removed from the finished article by methods which are harmless to the metal, e.g., by selective chemical attack.

Numerous materials which might be used as fillers are found to be unsatisfactory in practice when used with alloys which are difficult to work, particularly those alloys containing substantial amounts of nickel and chromium or nickel, chromium and cobalt which have good heat-resisting and creep-resisting properties and are commonly used for gas turbine blades and similar articles. For instance, graphite does not form coherent bodies which remain coherent and resistant to deformation during the plastic flow; copper and mild steel are too soft and so do not maintain the desired shape and size of the cavities; alloy steels are difficult to remove owing to their inherent resistance to chemical or electro-chemical attack by media which do not cause simultaneous damage to the alloy of the blade or the like; glass is too readily deformed; and sand has too large a grain size, tends to form irregular holes, has a deformability factor far removed from unity and has no tensile strength.

According to my invention the filler is a coherent body having a metal matrix with a refractory material dispersed throughout it and the deformability factor at the working temperature is not greater than 1.2 or less than 0.8, and is preferably not more than 1.1 nor less than 0.9. The metal of the filler must have a high melting point e.g. 1250° C. or above. Subject, of course, to the need for it to be removed after the hot-working without effect on the main metal, it may be iron, nickel, cobalt or chromium or any alloy of these. For reasons of price, pure iron is preferred.

The refractory material is preferably finely dispersed, i.e. is present as discrete particles while the metal matrix forms a continuous phase.

The purpose of the refractory phase is to enhance the resistance to deformation during working of the compound billet. The refractory phase must not melt, decompose or transform at the hot-working temperature, and it is preferably soluble in nitric acid, which is the most convenient corroding medium for dissolving and removing the metal of the filler without attacking nickel-chromium and similar alloys. It is not, however, essential that the refractory material should itself be soluble in acid, since if it is distributed as fine particles throughout an acid-soluble metal matrix the matrix will dissolve under acid attack and the refractory phase (if insoluble) will be removed as a fine powder. The preferred refractory constituent is magnesium oxide, which is acid-soluble, but the oxides of titanium, silicon, aluminium, thorium, zirconium and calcium may be used, as may sillimanite.

These fillers are particularly suitable for use with heat-resistant and creep-resistant alloys that are heated in use to 700° C. or above and contain at least 25% nickel +chromium or nickel+chromium+cobalt. The temperatures at which these alloys are worked are necessarily high, and even at these temperatures the alloys are difficult to deform.

The compound filler used according to my invention may be readily produced by well-known methods of powder metallurgy. The choice of matrix metal and refractory phase is limited by consideration of the compatibility of the components during production by powder metallurgy methods. In general, if a material is to be satisfactory as a filler it must enable holes of diameter about 1 to 2 mm. (not necessarily circular in section) to be extruded with substantially uniform cross-sectional shape and area throughout a considerable proportion of the length of the extruded product and with smooth inside surfaces, and must be easily removed.

I prefer to use a filler which consists of powdered magnesium oxide dispersed in a matrix of pure iron, the magnesium oxide amounting to from 5 to 25% by weight of the whole filler. Fillers of this kind can be used with advantage in billets of nickel-chromium or nickel-chromium-cobalt alloys containing titanium and aluminium, which are normally extruded at about 1200° C. Examples of such alloys are a nickel-chromium alloy containing from 18% to 21% chromium, from 1.8% to 2.7% titanium, from 0.5% to 1.8% aluminium, the balance being nearly all nickel, and a nickel-chromium-cobalt alloy containing from 18% to 21% chromium, from 15% to 21% cobalt, from 0.8% to 1.8% aluminium, from 1.8% to 2.7% titanium, the balance being nearly all nickel. If the content of magnesium oxide is less than 5%, the filler is too soft and deformable for use with these alloys, and if it is greater than 25% difficulty is experienced in making the filler into a coherent body. These preferred fillers can also be used in billets of austenitic stainless steels.

The stiffness of the iron-magnesia compositions at high temperatures increases with increasing proportions of the magnesium oxide, so the greater the resistance to deformation of the metal billet during hot-working, the greater should be the proportion of magnesium oxide. Iron-magnesia compositions containing 5% magnesia possess the great advantage that they can be swaged into the desired shapes, whereas compositions containing 15% magnesia must be machined. Swaging decreases the porosity of the compositions, thus reducing the deformability during further hot working. The deformability factor of a swaged filler consisting of 5% magnesium oxide and 95% pure iron used in either of the alloys quoted above as examples is 1.06, whereas a filler of the same composition in the unswaged condition had a deformability factor of 1.32. With the same alloys the deformability factor of an unswaged filler consisting of 20% magnesium oxide and 80% pure iron is 1.11 and the deformability factor of an unswaged filler consisting of 15% magnesium oxide and 85% pure iron is 1.16.

The preferred way of making the filler is intimately to mix powdered constituents of as small particle size as possible, form the mixture into compacts and sinter the compacts in a non-reducing atmosphere. In making the preferred composition, iron powder prepared by the thermal decomposition of iron carbonyl may be used, together with that grade of magnesia known as "light." In any case, the refractory particles are preferably smaller that the metal particles to ensure good bonding. The particle size of the metal powder may for example be from 2 microns to 10 microns, and that of the refractory powder for example from 0.1 micron to 2 microns. The powders may be intimately mixed by ball-milling, and then compressed into compacts under a pressure of, say, 10 tons per square inch. To reduce the risk of cracking of the compacts, camphor in an amount equal to 1% by weight of the mixture may be added during the mixing and be removed subsequently during a preliminary sintering in hydrogen at 600° C. The final sintering may be carried out at a temperature between 1200 and 1350° C.

for from 3 to 4 hours in an inert atmosphere, e.g. nitrogen, or in vacuo. If the final sintering is carried out in a reducing atmosphere, the density of the sintered composition is very considerably less.

The filler is readily removed after all operations, either hot or cold, by immersion of the article in aqueous solutions of 20 to 25% nitric acid with or without other mineral acids, e.g. with 1% hydrochloric acid, at temperatures from 85° C. to boiling point, without damage to the articles themselves.

The filler need not be preformed into a coherent body, since what is important is that it should be coherent during the extrusion. Therefore the coherent body may be formed from its constituents in situ. For instance a powder mixture of metal and the refractory material may be poured into the holes in the billet and compacting by ramming, being converted into the coherent body either during the heating prior to extrusion or by a separate heating operation. Again an unsintered compact may be inserted into each hole and similarly sintered before extrusion. However this formation of the coherent body in situ is not so satisfactory as the use of preformed coherent bodies, since it is easier to control the manufacture of these.

Those skilled in the art will appreciate that the present invention is applicable to the fabrication of numerous types and shapes of articles containing controllably-disposed internal passages or cavities which will usually be elongated in section and will have smooth walls.

Thus the invention may be used in the manufacture of lengths of metal which can be cut to form gas turbine blades or guide vanes. Such blades or vanes attain very high temperatures in operation and may have to be cooled. One method of cooling them is to force air through passages in them, and for this purpose the passages may have to run from the root to the tip of the blade or vane, i.e. along its span. Such passages should be at predetermined points in the cross-section and may have to differ from one another in cross-sectional shape. Thus blade or vane section in running lengths having one or more passages of very small cross-sectional area and predetermined shape, which cannot conveniently be made by machining, and possibly also with one or more passages of larger cross-sectional area for lightening purposes, may be made as follows:

A billet is provided with a number of axial holes and filled. It is important that the holes should not extend right through the billet to the leading end, since otherwise some of the filler will squirt forwards during the extrusion and be lost. Next the billet is raised to extrusion temperature, placed in the container of an extrusion press, and rotated so that the holes are correctly oriented with respect to a die of suitable section (preferably aerofoil section rather thicker than the desired final section). The billet is then extruded with external lubrication to ensure regular flow of the metal through the die. The extruded section still containing the filler is hot-rolled through shaped rolls to reduce the thickness and cut to lengths, and the filler is removed.

The present invention can also be used in producing tubing of thin wall thickness and small diameter by direct extrusion from a hollow billet containing the filler. Such tubing is used for sheathing electric heating elements, and is normally made by drawing a nickel-chromium, nickel-chromium-iron or other alloy in from ten to fifteen drawing passes. By using a filler according to the present invention it is possible to produce the tubing in a single step of extrusion, though if very fine tubing is required it can be obtained by re-extrusion through a smaller die without removal of the filler. Other types of tubing may also be made by processes of the kind described.

As another means whereby the present invention may be applied, a hollow blade having a number of cooling passages in its wall is made by assembling concentric tubes into a tubular unit having longitudinal passages between the tubes, drawing down this unit so as to reduce its diameter while retaining the passages, and deforming the unit into a hollow blade. The passages may be kept open during deformation by inserting therein the filler contemplated in accordance with the present invention. The filler may be put in the passages before the initial drawing down but preferably some reduction of the diameter of the unit is effected first to consolidate the tubes into a unit. Next the filler is put in the passages and then the deformation is effected by drawing until the unit is of desired diameter and wall thickness, and thereafter pressing or otherwise converting the unit, or an appropriate length out of it, to the cross-sectional shape required in the blade.

The tubular unit may be made from either two or three tubes. If three tubes are used, the outside and inside tubes are plain and the middle tube is corrugated sinusoidally or otherwise and is of such dimensions that it will make a push fit over the inside tube and in the outside tube. The passages are then formed on both sides of the middle tube by the spaces between the corrugations.

All three tubes may be of the same heat-resisting alloy, e.g. a creep-resistant nickel-chromium alloy, but to improve the heat-conductivity the middle tube may be of copper, or the outer surfaces of the inside and middle tubes may be copper-plated to allow the three tubes to be brazed together in the unit.

If two tubes are used, the passages are formed by longitudinal indentations in the inner wall of the outside tube or the outer wall of the inside tube, or preferably, by indentations in both those walls, the indentations in the one being brought into register with those in the other to form the passages.

During the deformation of the unit, whether it be composed of two tubes or three, the wall may be drawn down so that it tapers in thickness if a tapering blade section is required.

The filler material comprising the present invention may also be employed for the production of hollow turbine blades and other blades having an integral root and containing cooling passages in the walls thereof. When this process is carried out to produce a hollow blade, a hollow metal slug containing a plurality of longitudinal holes in the wall thereof filled with the filler material contemplated by the present invention is prepared and is then extruded from a container through an opening having the cross-sectional shape required for a turbine blade. The extrusion is stopped when enough metal has been forced through the opening to form the blade and while enough metal remains in the body cavity to form the root. The extruded product may then be pulled out rearwardly from the die or a split die may be employed which can be opened to remove the product. The central hole or holes in the extruded blade may be held open during extrusion, if desired, by means of an extrusion ram having one or more forward extensions or spigots corresponding in cross-section to the desired contour of the center hole or holes required in the hollow blade.

The filler material contemplated in accordance with the present invention may also be employed in the production of turbine wheel discs containing passages or cavities at pre-determined locations therein or even to the production of hollow discs. When this process is carried out, one or more holes are prepared in an extrusion billet and the filler contemplated in accordance with the present invention is inserted in the holes. The billet is then subjected to axial pressure to deform the billet in a die having an opening all around the bottom, said opening leading to an annular cavity so that the metal in the die flows radially through the opening into the annular cavity and becomes disc-shaped. The filler moves radially with the metal so that, in the resultant disc, the filler extends from the surface at the end through which the holes were made originally to points close to the outer cylindrical

surface of the disc. In other words, the filler now lies in holes which run partially axially and partially radially. In this manner, cooling passages may be provided in a turbine rotor disc by which a cooling agent may flow to the roots of the blades of a gas turbine motor.

It is of course necessary that axial holes made in the original billet should lie at such a radial distance from the axis that they will be within the metal of the disc produced. It may be desirable to drill the holes so that they lie on the surface of a cone within the billet, the apex of the cone facing the ram used for the deformation, so that the filler in the holes will more readily move radially when the axial pressure is applied.

Another way of making cooling passages in a gas turbine rotor is to drill axial holes from one end of the billet to the other and deform the billet by opposed rams acting on the two ends of the billet. Then each filled hole in the deformed billet will be substantially of U shape with two short lengths at right angles to the arms of the U, these lengths and the base of the U being substantially parallel to the axis. The bases of the U's must then be exposed in the same way as the ends of the holes in the method described above.

A further way of making cooling passages is to drill radial holes in the middle of the billet to communicate with a single central hole, which may be made in the billet and filled, or may be made subsequently in the disc produced from the billet.

If the fillers do not move identically during the deformation, the resultant disc may be dynamically out of balance, i.e. its centre of gravity may be slightly eccentric. This can be rectified by enlarging one or more of the holes in the disc after removal of the filler.

The invention may also be employed in producing rotor discs of light weight. In such a case a single large hole may be made along the axis of the billet but not completely through it, and in the extrusion the filler within the hole will be converted into disc shape, the filler disc lying centrally within the metal disc. After the removal of the filler the central hole leading to the cavity within the disc may be tapped to receive the end of the rotor shaft, or either, the faces or each face of the disc may be recessed to receive a flanged shaft which is bolted or welded in position. Alternatively, a single large hole may be made completely through the billet and two opposed rams may then be used to produce a hollow disc with an opening at each face.

It will be appreciated that when any of the foregoing processes is carried out, the filler material contemplated in accordance with the present invention may readily be removed, for example, by chemical or electrochemical means, without damage to the hot-worked article. When the filler material is removed, passages are provided in the hot-worked articles which have smooth walls and which are controllably disposed within the hot-worked article.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

I claim:

1. A hot-workable, heat-resisting metal body containing at least one hole filled with a coherent filler said filler consisting essentially of a continuous matrix of iron group metal and discrete particles of a refractory selected from the group consisting of magnesium oxide, titanium oxide, silicon oxide, aluminum oxide, thorium oxide, zirconium oxide, calcium oxide and sillimanite dispersed throughout said matrix and said filler having a deformability factor at hot working temperatures with respect to said heat-resisting metal between about 0.8 and about 1.2.

2. A hot-workable, heat-resisting metal body containing at least one hole filled with a coherent filler said filler consisting essentially of a continuous matrix of iron group metal and from about 5% to about 25% by weight of discrete particles of magnesium oxide dispersed throughout said matrix and said filler having a deformability factor at hot working temperatures with respect to said heat-resisting metal between about 0.8 and about 1.2.

3. A hot-workable, heat-resisting metal body containing at least one hole filled with a coherent filler said filler consisting essentially of a continuous matrix of iron and from about 5% to about 25% of discrete particles of magnesium oxide dispersed throughout said matrix and said filler having a deformability factor at hot working temperatures with respect to said heat-resisting metal between about 0.8 and about 1.2.

References Cited in the file of this patent

UNITED STATES PATENTS

1,826,456	Comstock	Oct. 6, 1931
2,021,945	Payne	Nov. 26, 1935
2,047,555	Gardner	July 14, 1936
2,317,786	Tubbe	Apr. 27, 1943
2,404,598	Sachse	July 23, 1946
2,431,660	Gaudenzi	Nov. 25, 1947
2,488,731	Lambert et al.	Nov. 22, 1949
2,609,576	Roush et al.	Sept. 9, 1952
2,628,417	Peyches	Feb. 17, 1953
2,698,990	Conant et al.	Jan. 11, 1955
2,783,530	Conant	Mar. 5, 1957

FOREIGN PATENTS

580,744	Great Britain	Sept. 18, 1946
733,061	Great Britain	July 6, 1955