0337DEL14 05 FEB 2014

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ABSTRACT

Title: Collapsible Mandrel for Casting of Composite propellant grain having complicated port geometry

The present invention relates to a novel mandrel for the casting of composite propellant grain having complicated port geometry / configuration such as *fin-o-cyl* and a method for preparation of the novel mandrel.

Figure 6

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WE CLAIM

1. A method for the preparation of a mandrel for casting of the composite propellant grain having complicated port geometry comprising the steps of:
    a. Assembling a die on a substantially cylindrical mandrel whereby said mandrel having a channel placed inside the said mandrel in an essentially concentric manner with an opening at its one end, said channel extending to a desired distance within the mandrel and projecting radially outward to open as outlets from the mandrel such that the outlets of the channel open into the cavities provided in the said die so as to facilitate desired shape of protrusions of the mandrel giving complicated port geometry in the composite propellant grain to be cast on the mandrel;
    b. Positioning a funnel with solid eutectic alloy with a melting point of 60 – 70 °C with the die-mandrel assembly at the opening of the channel of the mandrel and placing the entire assembly within an oven at a temperature of at least 70°C so as to ensure that the eutectic alloy is in the molten state or alternatively pouring molten eutectic alloy with a melting point of 60-70°C into the funnel;
    c. Allowing the die cavities to be filled;
    d. Cooling down the assembly so as to ensure that the molten alloy solidifies and takes the desired shape of the cavity of the die;
    e. Disassembling the die from the mandrel.

2. The method as claimed in claim 1 wherein the solid eutectic alloy having a melting point of 60-70°C selected is either an alloy of Indium and Bismuth or Indium, Bismuth and Tin.

3. The method as claimed in claim 2 wherein the solid eutectic alloy is an alloy of Indium and Bismuth and the amount of Indium in the alloy is in

the range of 65-68 % (w/w) and the amount of Bismuth in the alloy is in the range of 32-35 % (w/w).

4. The method as claimed in claim 2 wherein the solid eutectic alloy is an alloy of Indium, Bismuth and Tin and the amount of Indium in the alloy is in the range of 52-57% (w/w), Bismuth is in the range of 30-35 % (w/w) and Tin is in the range of 11-18 % (w/w).

5. The method as claimed in claim 1 wherein the cylindrical mandrel of step (i) is made of a material selected from mild steel, stainless steel or aluminium externally coated with Teflon.

6. The method as claimed in claim 5 wherein the material of mandrel is preferably aluminium externally coated with Teflon.

7. The method as claimed in any one of the preceding claims wherein the die selected is designed considering the thermal coefficient expansion of the eutectic alloy.

8. The method as claimed in any one of the preceding claims wherein the die used is a split-type die.

9. The mandrel for casting of the composite propellant grain having complicated port geometry prepared by the method as claimed in claim 1.

Dated this the 3rd day of February 2014

Dominic Alvares
Of S. Majumdar & Co.
Applicant's Agent

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Applicant: Director General, Defence Research & Development Organisation

7 SHEETS
SHEET 1

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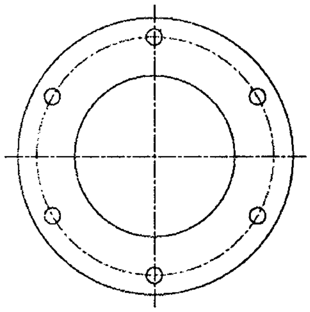

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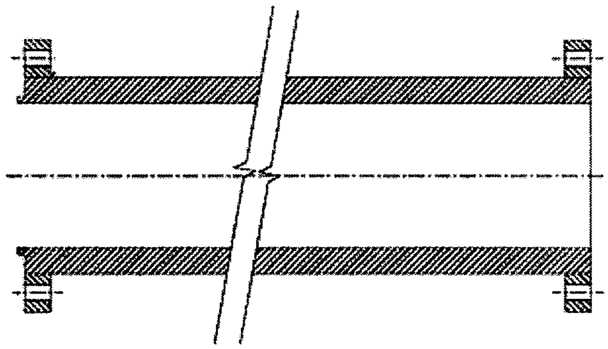

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Figure 1

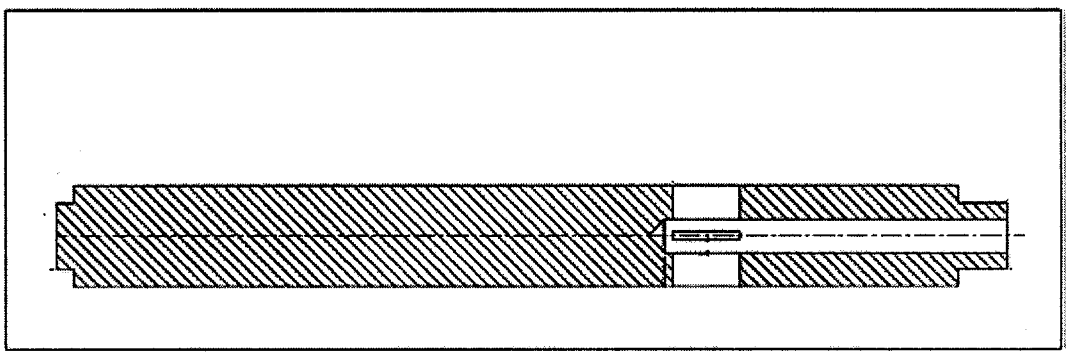

Figure 2

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SHEET 2

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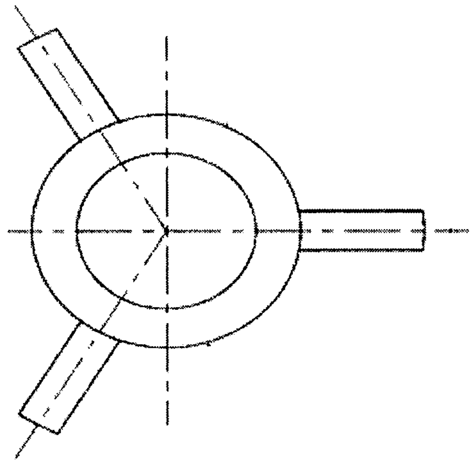

Figure 3

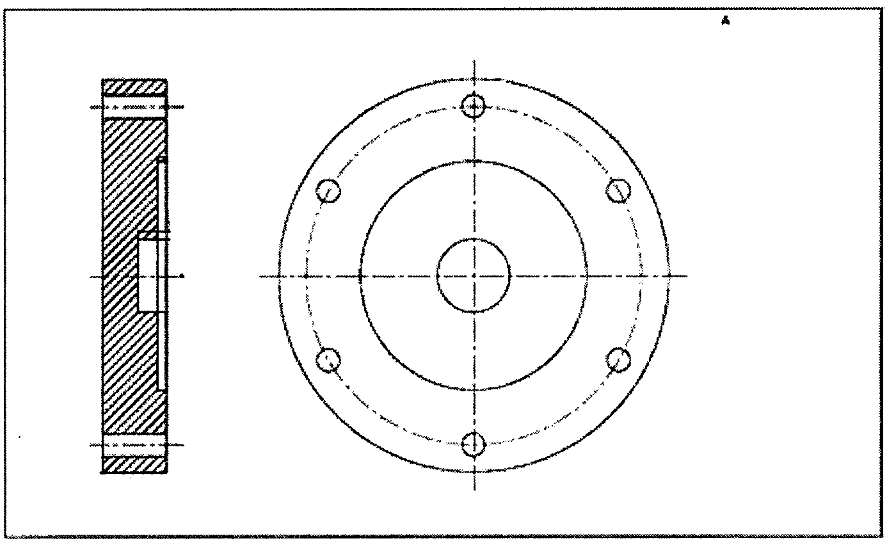

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Figure 4

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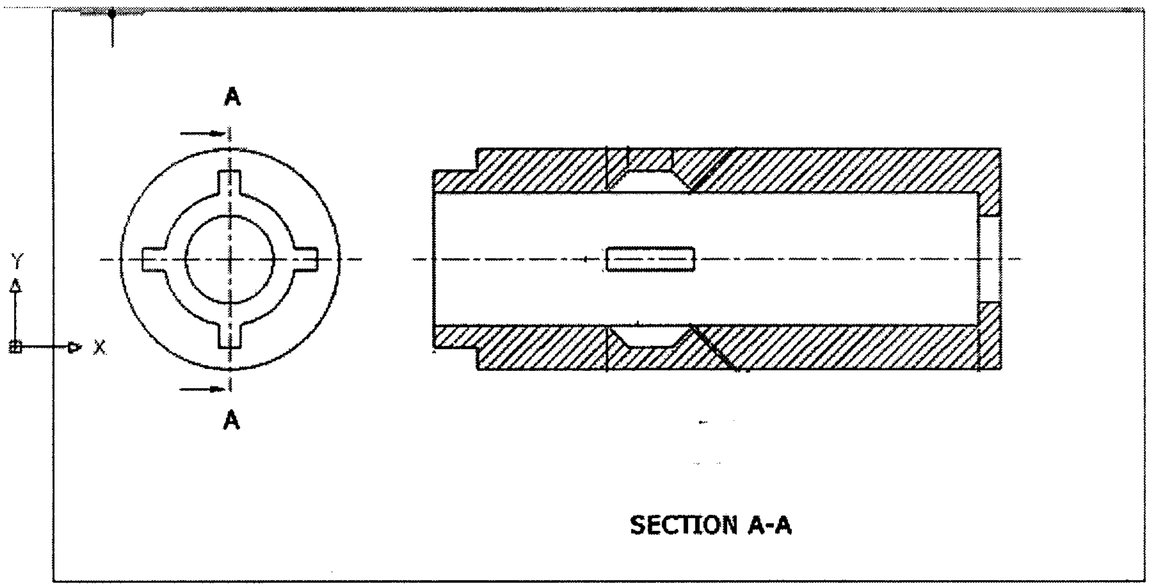

A B

Figure 5

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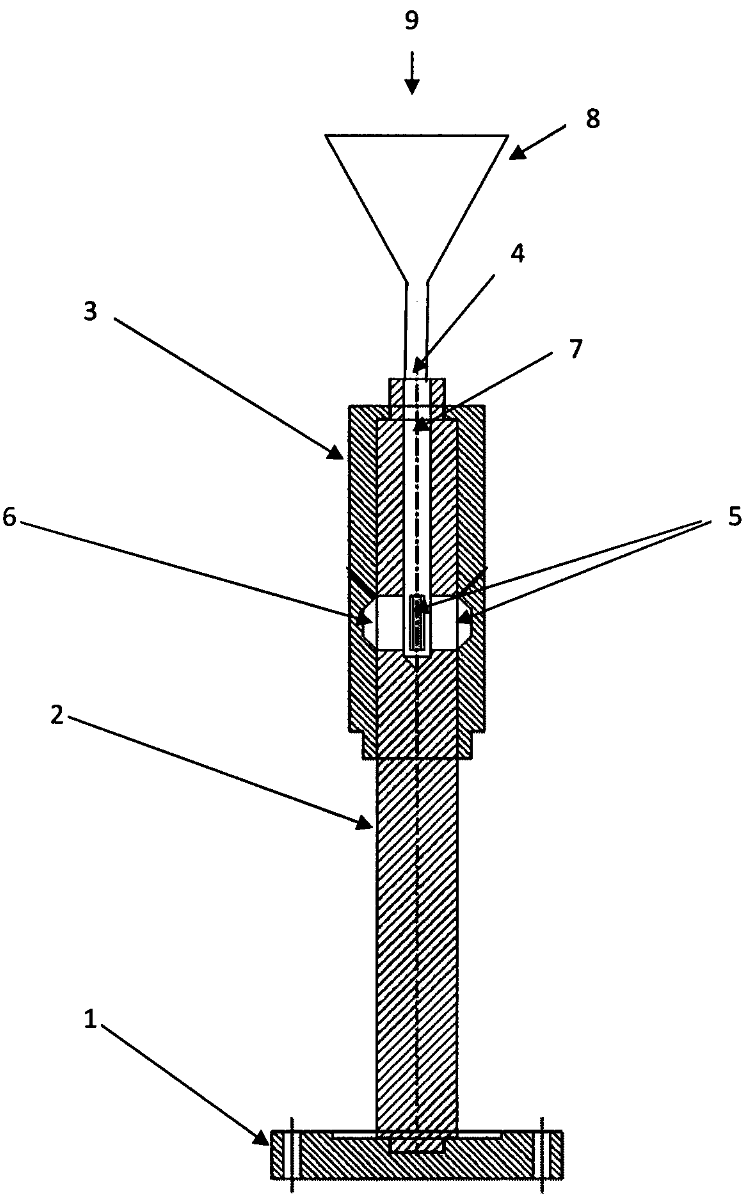

Figure 6

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SHEET 5
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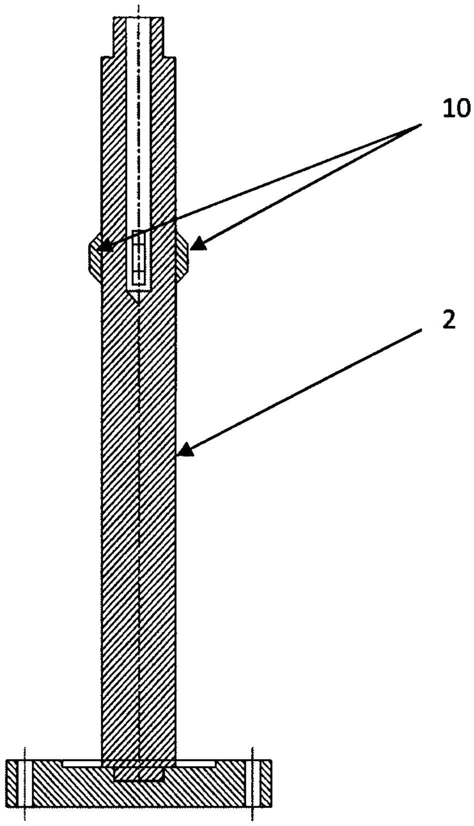

Figure 7

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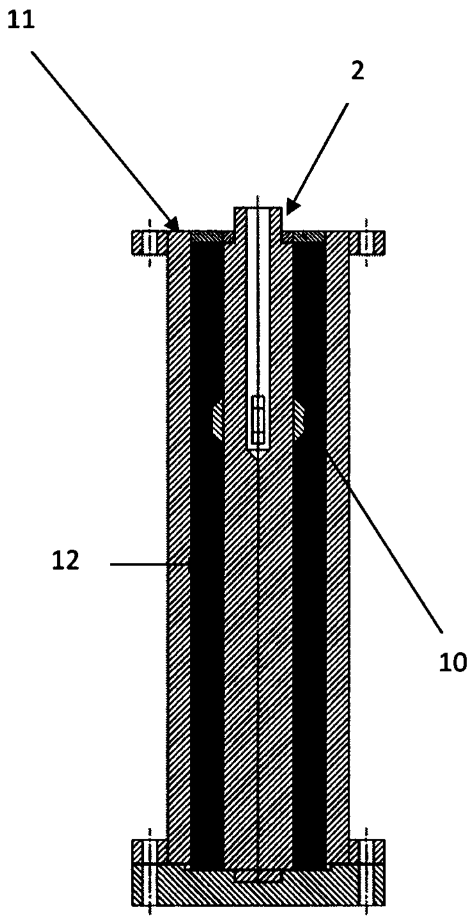

Figure 8

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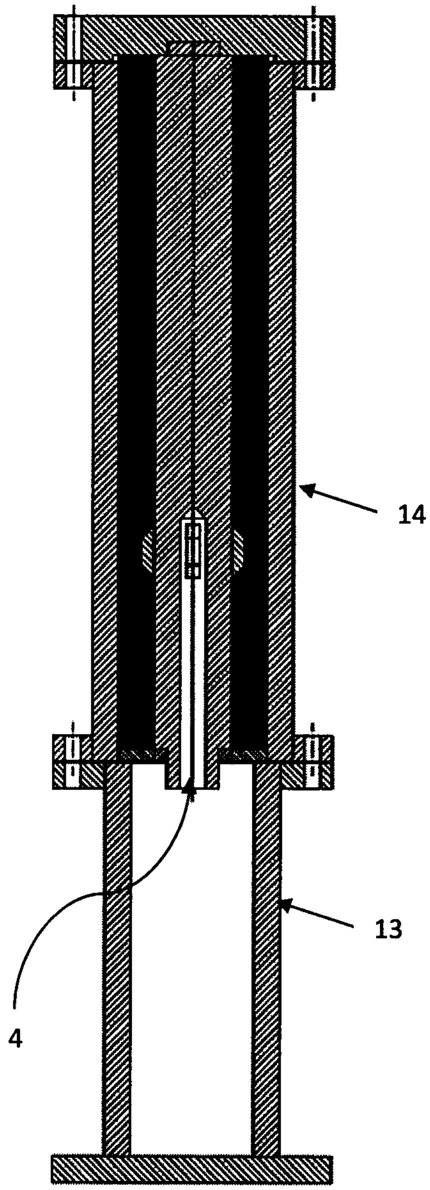

Figure 9

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FIELD OF THE INVENTION

The present invention relates to a mandrel for the casting of composite propellant grain having complicated port geometry / configuration such as *fin-o-cyl* and a method for preparation of the mandrel.

BACKGROUND OF THE INVENTION

Modern solid rocket propellant in use are composite propellants which comprise of solid oxidizer (ammonium perchlorate, potassium perchlorate etc.), metal fuel (aluminum powder, zirconium powder) and binders (Hydroxyl/carboxyl terminated poly butadiene pre-polymer with isocyanate based curing agent) which also act as fuel.

In chemical rocket motors, when propellant burns, a large amount of gaseous products and heat is generated. These high velocity gaseous products flow out of nozzle and thrust is generated which propels the rocket motor. In liquid propellant the thrust is controlled by adjusting the flow rate of liquid propellant in combustor. But in solid rocket motors the propellant burns layer by layer hence it is not possible to control or alter the thrust during the flight. To get desired thrust characteristic, the configuration of propellant grain is evolved in such a manner so as to give precise mass flow during combustion.

There are approaches where different kinds of collapsible core are used to tailor the configuration of propellant. A method for manufacturing solid rocket motors comprises placing a mandrel having at least one collapsible solid slot former positioned thereon substantially centrally along the axis of a rocket motor case, casting uncured solid rocket propellant about the mandrel and the collapsible solid slot former, curing the solid propellant, removing the mandrel and pressurizing the propellant and slot former, causing the slot former to collapse, and remove from cured propellant [US Patent 6101948].

A breakdown core for forming a cavity in solid propellant grain [US Patent: 3567174], that is larger in diameter than the opening in the aft end of a rocket motor case, and wherein the core comprises a body and plurality of vanes or fins that are selectively connected to the body by utilization of permanent magnets.

For larger propulsion system, where mandrel weight is high and handling is difficult, collapsible mandrel [US Patent: 3237913] is used, which is lighter in weight than solid mandrel. After curing of propellant mandrel is disassembled as required from any location. Rigid segmented mandrel and collapsible mandrel [US Patent: 5266137, 4233020] is used for similar application for manufacturing large diameter pipes, tanks or vessels.

Alloy mandrel/core [US Patent: 5263531] is used in a process for manufacturing an article of thermosetting resins reinforced by fibers [US Patent: 4822272]. This alloy is rigid at the room temperature and shows good plasticity at temperature above 180°C. This alloy contains 78% by weight of zinc and 22% by weight of aluminum. The said documents also does not disclose about the use of solid propellant grain preparation. This alloy reaches the plastic state at significantly high temperature; hence it cannot be used for composite propellant casting due to its sensitivity and explosive nature at elevated temperature.

The auto-ignition temperature of the composite propellant grain is in range of 180-240°C.

Extraction of mandrel from cured rocket motor propellant is a hazardous operation. The mandrel (also known by the name 'core') thus designed should be capable of giving desired port geometry / configuration to the grain and should be safe and easy to extract.

The said mandrel can also be used in a method of manufacturing of vessels, tanks, reactors and articles where material of construction is sensitive to exposure of a temperature usually around 75°C or above.

WO2009/149108 entitled 'Inflatable Medical Devices' discloses that the mandrel may be made from a low melting point wax or metal, a foam, some collapsing structure or an inflatable bladder. The mandrel can be made from a eutectic or non-eutectic bismuth alloy and removed by raising the temperature to the melt point of the metal. The mandrel can be made from aluminum, glass, sugar, salt, corn syrup, hydroxypropylcellulose, ambergum, polyvinyl alcohol (PVA, PVAL or PVOH), hydroxypropyl methyl celluslose, polyglycolic acid, a ceramic powder, wax, ballistic gelatin, polylactic acid, polycaprolactone or combinations thereof. The said document discloses a variety of low melting point materials from which the mandrel can be made and which cannot be used for casting of the propellant grain. In one embodiment the document discloses the use of a eutectic and non-eutectic alloy. However, the entire mandrel is made of the material. While the said mandrel may be capable of use in the making of medical devices, for rocket motor processing mandrels which can be of very large size, in case the entire mandrel is made with eutectic alloy the cost of the mandrel and weight will be very high.

The composite propellant grain of the present invention can be case bonded or cartridge loaded. It is very difficult to give intricate internal port shape to the propellant grain of *wide range of sizes* using conventional casting and extraction techniques. For the preparation of a propellant grain with very complex geometry e.g. *fin-o-cyl* geometry where fins are positioned in middle and cylinder at both ends, where it is not possible to be extract the mandrel easily and safely after curing of propellant, there arises a need to develop a technique to prepare a mandrel, which mandrel so prepared is such which can impart the desired geometry and which can be extracted safely and used to economically cast propellant grain of varying sizes. The mandrel of the present invention is made of special alloy and which mandrel can be easily extracted after casting of propellant grain by melting the alloy in the mandrel at very safe temperature 60°C to 70°C without hazard. The mandrel of the present invention includes metallic alloy which has special characteristic of melting at low temperature ~ 60 to 70 °C and thus can be used for low temperature casting of composition propellant grain having complicated port geometry. After curing of propellant at moderate temperature around 45-55°C, the complete assembly is exposed to temperature which is just sufficient to melt the alloy, and give the desired geometry of composite propellant grain port.

The advantage of the present invention is that it is a very simple and safe to prepare and extract mandrel from rocket motor and this technique can be used for case bonded and cartridge loaded propellant grains. It can also be used to fabricate tank, vessel or containers having complicated geometry where material of construction is sensitive to exposure of a temperature greater than 75°C.

OBJECT OF THE INVENTION

It is an object of the present invention to develop a processing technique for preparing mandrel with eutectic alloy which is an alloy of Bismuth and Indium or Bismuth, Indium and tin and having a melting temperature of 60 - 70 °C.

It is another object of the present invention for the casting of the propellant grain which has highly complicated port geometry (configuration).

It is yet another object of the present invention to extract or de-core the mandrel by melting the alloy mandrel.

It is a still further another object of the present invention to establish a technique for extracting or de-coring mandrel safely, eliminating friction due to movement of solid mandrel.

It is also another object of the present invention to give a propellant grain having fin shape in middle of grain and cylindrical shape at both ends i.e. fin-o-cyl.

It is yet another object of the present invention to manufacture propellant grain of any shape and size using eutectic alloy mandrel of the present invention.

SUMMARY OF THE INVENTION

According to one aspect of the present invention there is provided a method for the preparation of a mandrel for casting of the composite propellant grain having complicated port geometry comprising the steps of:

a. Assembling a die on a substantially cylindrical mandrel whereby said mandrel having a channel placed inside the said mandrel in an essentially concentric manner with an opening at its one end, said channel extending to a desired distance within the mandrel and projecting radially outward to open as outlets from the mandrel such that the outlets of the channel open into the cavities provided in the said die so as to facilitate desired shape of protrusions of the mandrel giving complicated port geometry in the composite propellant grain to be cast on the mandrel;
b. Positioning a funnel with solid eutectic alloy with a melting point of 60 – 70 °C with the die-mandrel assembly at the opening of the channel of the mandrel and placing the entire assembly within an oven at a temperature of at least 70° C so as to ensure that the eutectic alloy is in the molten state or alternatively pouring molten eutectic alloy with a melting point of 60-70 °C into the funnel;
c. Allowing the die cavities to be filled;
d. Cooling down the assembly so as to ensure that the molten alloy solidifies and takes the desired shape of the cavity of the die;
e. Disassembling the die from the mandrel.

According to another aspect of the present invention there is provided a mandrel for the casting of composite propellant grain having complicated port geometry.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

In the appended drawings:

Figure 1 illustrates a Mould;

Figure 2 illustrates a Mandrel to be used for preparing the mandrel with eutectic alloy fins;

Figure 3 illustrates a Centering Ring;

Figure 4 illustrates a Base Plate;

Figure 5 illustrates a Split-type Die;

Figure 6 illustrates a Die Mandrel Assembly;

Figure 7 illustrates a Mandrel with Eutectic alloy fins;

Figure 8 illustrates a Mould assembly with propellant;

Figure 9 illustrates a Mould assembly for extraction of alloy fins to be kept in oven upside down at 70°C.

DETAILED DESCRIPTION OF THE ACCOMPANYING DRAWINGS

The following drawings are illustrative of particular examples for enabling methods of the present invention, are descriptive of some of the methods, and are not intended to limit the scope of the invention. The drawings are not to scale (unless so stated) and are intended for use in conjunction with the explanations in the following detailed description.

Reference is first invited to Figure 1 where the mould is shown i.e. top view (Figure 1A) and sectional view of the mould placed horizontally (Figure 1B).

Figure 2 shows another view of the sectional view of the mandrel to be used for preparing the mandrel with eutectic alloy fins placed horizontally.

Figure 3 shows the top view of the centering ring.

Figure 4 shows the sectional view of the base plate placed vertically (Figure 4A) and top view of the base plate (Figure 4B).

Figure 5 shows the top view of the split-type die (Figure 5A) and sectional view of the said die placed horizontally and split along A-A axis i.e. the axis along which the split-type die is split. (Figure 5B).

Figure 6 is the detailed sectional view of the die mandrel assembly placed vertically which is used for the preparation of the mandrel with eutectic alloy fins.

Figure 7 is the sectional view of the mandrel with eutectic alloy fins attached to the base plate.

Figure 8 is the sectional view of the mould assembly with the composite propellant depicting as to how the propellant is moulded around the mandrel with the eutectic alloy fins to give the desired port geometry to the propellant grain.

Figure 9 is sectional view of the mould assembly for extraction to be kept in an oven at 70°C.

The invention thus provides the method for preparing a mandrel with eutectic alloy fins which can be used for the casting of composite propellant grain having complicated port geometry.

DETAILED DESCRIPTION OF THE INVENTION

In accordance with the present invention, a method is provided for preparing mandrel for casting the composite propellant slurry in case bonded motor or as cartridge loaded grain and extracting it at very low and safe temperature (60°C to 70°C) i.e. significantly lower than the auto-ignition temperature which is in the range of 180-240°C. Almost all solid propellant consists of approximately 87-90 % (w/w) (i.e. weight by weight is represented as 'w/w') solids and 10-13 % (w/w) cross-linking binder. Out of solid 67 to 80 % (w/w) is ammonium perchlorate, 0 to 17 % (w/w) aluminum powder and there are small quantities of other additives like burn rate catalyst, combustion stabilizers etc depending upon the required ballistics properties. The mandrel is prepared by using conventional metal casting technique in a die. But the material used for preparing the protrusions on the mandrel for providing the complex pore geometry in the composite propellant grain is special alloy of Indium [65-68 % (w/w)] and Bismuth [32-35 % (w/w)]. This type of alloy is called eutectic alloy. This alloy has very low melting temperature of 60 - 70 °C. Another such alloy has melting temperature of 60 – 70°C, and it contains Indium 52-57 % (w/w), Bismuth 30-35 % (w/w) and Tin 11-18 % (w/w). The eutectic alloy of the present invention is such that the melting temperature is significantly lower than the auto-ignition temperature of the composite propellant grain but higher than curing temperature by 5-10°C. Mandrels from various materials can be made such as from mild steel (MS), stainless steel (SS) or aluminium *externally* coated with Teflon. Main cylindrical part of mandrel is made of Aluminum which is *externally* coated with Teflon (i.e. the internal channel of mandrel is not coated with Teflon). However, the use of aluminium externally coated with Teflon is preferred since aluminum is light weight, soft metal which less tendency to produce spark while metal-metal contacts and Teflon ensures easy release of the propellant after curing. The solid eutectic alloy with a melting point of 60 – 70 °C is either positioning in a funnel with the die-mandrel assembly at the opening of the channel of the mandrel (as described below) and placing the entire assembly within an oven at a temperature of at least 70°C so as to ensure that the eutectic alloy is in the molten state or alternatively pouring melting and pouring the solid eutectic alloy with a melting point of 60 – 70 °C into the funnel positioned on the die mandrel assembly at the opening of the channel of the mandrel so that the alloy reaches the die cavities to achieve the required shape of mandrel fins/protrusion.

It is known in the art and it is preferable that the die selected is designed considering the thermal coefficient expansion of the material to be molded such as of the eutectic alloy. Once the mandrel is prepared propellant casting is done. Once the curing is over the extraction of mandrel becomes very easy when the complete mould with mandrel and cured propellant is exposed to a temperature which is just equivalent or higher than the melting temperature of alloy. Alloy flows out through the opening of the mandrel just like liquid without affecting any characteristic and shape of the propellant which has been cast.

The eutectic alloys used in the present invention are exemplified herein below, which are only illustrative in nature and should not be construed to limit the scope of the invention in any manner.

Eutectic Alloy composition % (w/w)	**Melting point °C**	**Thermal coefficient of expansion (linear)** $10^{-6}\ K^{-1}$
66.3 % (w/w) of indium + 33.7% (w/w) of bismuth	70	22
55.5 % (w/w) of indium + 33.5% (w/w) of bismuth +11 % (w/w) of tin	60	21

In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and illustrate the best mode presently contemplated for carrying out the invention. Further use of the mandrel has been discussed below to describe a way the mandrel of the present invention can be used. However, such description should not be considered as any limitation of scope of the present invention. The structure thus conceived is susceptible of numerous modifications and variations, all the details may furthermore be replaced with elements having technical equivalence.

In this invention the main emphasis is on a mandrel, its preparation and its particular advantage for the safe and non-hazardous extraction/de-coring of the mandrel after complete curing of the composite propellant grain after casting of the said grain. The figure 6 depicts the process of preparation of the mandrel and figure 9 depicts the extraction process of the mandrel after casting the composite propellant grain.

The set-up for Preparation of the Mandrel and subsequent Low temperature melt cast technique for casting of composite propellant grain comprises of:

1. Double Walled Hot Water Circulating Oven: It is the oven in which hot water circulation is used for maintaining the temperature inside oven. It is utilized for preparation of mandrel, curing of propellant, and extraction/de-coring of alloy mandrel by heating up to melting point of eutectic alloy. Ovens such as double walled hot water circulating oven are commonly and commercially available.
2. Mandrel (Figure 2): This mandrel is designed in a manner to achieve a propellant grain with complicated port geometry. Fins of this mandrel are prepared by die casting of eutectic alloy. The cylindrical part of mandrel is made of aluminum. A channel is provided at the center of the mandrel (inside the mandrel) in an essentially concentric manner with an opening at its one end, said channel extending to a desired distance within the mandrel and projecting radially outward to open as outlets from the

mandrel for allowing the passage of eutectic alloy which will be in molten state at 70°C.

3. Split-type Die (Figure 5): It is the die used for giving the desired shape of fins (protrusions) of the mandrel.
4. Die Mandrel Assembly (Figure 6): The die (3) is assembled with mandrel (2) such that each outlet (5) of the mandrel opens up into each respective die cavity (6) and the molten alloy is poured (9) in funnel (8), through which it reaches the internal channel of mandrel (7) through the opening of the mandrel (4) and takes the shape as per die cavity (6) after cooling. Complete assembly (Figure 6) may be kept inside oven at temperature of around 70°C, in which case the solid alloy is kept in funnel (8) and due to low its melting temperature it slowly melts and fills the die cavity (6).
5. Vacuum Casting Chamber: It is a pressure vessel designed to withstand full vacuum. The purpose of this chamber is to deaerate the slurry while casting. A pressure of 3-4 Torr absolute is maintained in the chamber throughout the deaerating process.
6. Mould (Figure 1): It is assembled with other parts like mandrel (with alloy fins), base plate and centering ring. The composite propellant slurry is cast into the mould.
7. Base Plate (Figure 3): It is designed to facilitate casting of propellant slurry in mould with mandrel.
8. Centering Ring (Figure 4): The purpose of centering ring is to fix the mandrel concentrically inside the mould.

<u>Steps involved in the Preparation of the mandrel with eutectic alloy and its subsequent use in Low Temperature Melt Cast Technique:</u>

<u>1. Preparation of mandrel with alloy fins:</u>

Main cylindrical part of mandrel (2) is made of Aluminum which is Teflon coated. Die (Material of construction: mild steel) (3) is assembled with the mandrel, as depicted in Figure 6, to give the *fin-o-cyl* configuration with four symmetrically positioned fins. This assembly is kept in an oven at 70°C. The funnel (8) having eutectic alloy is also positioned along with the assembly. As the temperature reaches the melting temperature of alloy, it starts melting and fills the cavity of die (6). After the die is filled, the assembly is allowed to cool down gradually. As the temperature reduces, the molten alloy gets solidified and takes the desired shape. The die is then removed from the mandrel. Final shape of mandrel is shown in Figure 7 i.e. with fins (10).

2. Preparation of composite propellant slurry:

Composite Propellant slurry is prepared by mixing all solid ingredients in pre-polymer resin. Vertical Planetary mixer is used for this operation. After ensuring homogeneity and moisture content of propellant slurry curative (Iso cyanate) is added. When curative is also homogeneously mixed the propellant slurry is ready for casting.

3. Preparation of final assembly of mould and mandrel for propellant casting:

The mandrel which has the eutectic alloy fins (10) is inspected for any visual defect on surface. The mould (11) and mandrel (2) with fins (10) are assembled as shown in Figure 8 and are kept in vacuum casting chamber for propellant casting.

4. Casting of propellant slurry in mould:

Complete mould assembly (Figure 8) is positioned inside the vacuum chamber for casting and vacuum is applied in the vacuum casting chamber through oil ring vacuum pump till the pressure inside the chamber reaches 3-4 Torr absolute. The propellant slurry is casted in mould with this typical vacuum casting method. Casting can also be done by other methods like plunging mandrel or pressure casting.

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5. Propellant curing:

The mould (11) filled with propellant (12) i.e. the mould assembly with propellant (Figure 8) is kept in curing oven at appropriate temperature and for the required duration for curing of the propellant. The temperature at which the propellant is cured should be at least 5°C lower than the melting point of the alloy used for preparing the mandrel.

6. Extraction:

After propellant curing is completed, oven temperature is raised to melting point of eutectic alloy and the mould is kept upside down (Figure 9). As the temperature reaches melting point of alloy, it will start melting and will come out on its own through the opening of the mandrel (4). It is collected at the bottom in a container (13). Collected alloy can be re-used for mandrel preparation. Once the alloy fins are removed, the cylindrical Teflon coated mandrel can be easily and safely removed.