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COMBUSTION SYSTEM COMPRISING METAL FOIL AND SOLID PERCHLORATE

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This invention relates to composite solid fuels employing aluminum or other metal foil as a component. More particularly, the invention concerns novel solid composite rocket and ramjet propellants containing aluminum foil in conjunction with one or more other fuel components and oxidizers, and in which the foil performs both mechanical and fuel functions.

In accordance with the present invention it has been found that metal foil, and particularly aluminum foil, may be employed in the preparation of solid fuels, in such manner as to enhance materially the ignition and burning rate characteristics of such fuels. This improvement in the fuel characteristics is attributable not only to the comparatively high heat of combustion of metallic aluminum which enables it to serve as an auxiliary fuel component, but also to the high reflectance properties of aluminum foil, by which the metal serves to concentrate the heat developed by the other fuel components. Thus, the presence of aluminum and other metal foils greatly increases the overall efficiency of a given solid fuel.

It has been further found, in accordance with this invention, that aluminum and other metal foils, such as, for example, magnesium foil, may be employed in conjunction with solid fuels, such as composite rocket or ramjet fuels, in several different ways. Thus, for example, a fuel or power package comprising a particular aluminum foil, together with a suitable solid oxidizer therefor, may be prepared by forming a sandwich or a coil of aluminum foil, in which thin layers of the solid fuel and oxidizer are disposed or distributed between the alternate layers or concentric or spiral turns of the aluminum foil. When used in this manner, the aluminum or other metal foil imparts a high degree of mechanical strength to the fuel package, eliminating the necessity for using organic binders, wire stringers and the like for holding the package together. Here also the high reflecting surface of the aluminum, which reflects up to 90 to 95 percent of the radiant energy and heat of fuel combustion developed within the concentric folds of the rolled foil, serves to intensify the ignition and burning effects. There is a time gradient before the adjacent layer starts to burn and in this interval the reflecting characteristics still function.

Another important improvement offered by this invention is the prevention of explosive propagation of burning throughout the whole package. It is known that a high degree of densification is necessary with conventional mixtures of aluminum powder and oxidant in order to avoid explosion and keep the propagation of combustion under control. If, for example, aluminum powder of about 325 mesh or finer is mixed with NH_4ClO_4 powder, the apparent density as achieved by free flow e.g. into a container is around 1 gr./ccm. The burning of such mixture cannot be controlled. Once the ignition has started at one point, the hot gases fill the adjacent voids and heat the whole mass so quickly that it detonates. It is therefore common practice to compress such mixtures with sufficient specific pressure to achieve an apparent density of around 2 gr./ccm. or higher. This requires heavy press equipment. Such compressed so-called "grain" often needs a binder in order to keep it mechanically in shape. Also, the operation of compression is hazardous and requires strict safety measures.

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In contrast, with this invention, the mixture of oxidant and powdered or granular combustible aluminum or aluminum alloy is preferably used loosely between metal foil layers, e.g. aluminum foil. The latter serve as safeguards against the penetration of hot gases throughout the mass, and thereby allow fast combustion of individual loose fuel layers, having an apparent density below 2 gr./ccm. Hot gases from the combustion of such separate distinct quantities cannot penetrate to the next layer, because of the resistance offered by the foil for a small but decidedly substantial increment of time. In this small increment of time, the foil reflects heat, likewise absorbing heat until it melts and opens the gate to the next partition, simultaneously now burning itself. The rate of combustion throughout the package is controlled by controlling the weight of fuel being disposed between the individual layers of the metal foil, and the thickness of the foil. By this method the hazardous and costly step of compressing is avoided. The fuel is used in its highest form of reactivity, however without the risk of explosion.

It is evident that commonly known compressed fuel mixtures of the above kind cannot burn faster than the limit, given by their apparent density. Otherwise, they would detonate. In contrast, this invention approaches any desired fast rate, short of explosion, by keeping the fuel mixture in loose and therefore highly reactive form and hindering the propagation by the foil. Since the specific impulse of fuel packages depends on the thrust being developed per second, the new method allows to produce a package of improved specific impulse, e.g. more than 250 lb. sec./lb.

Aluminum foil discs may be used to seal the above described power package by bonding the discs to each end face of the coiled aluminum foil containing the fuel and oxidizer, thus preserving the contents of the package from corrosion on storage and also reducing hazards and imparting ease of handling. Ignition may be started by means of any conventional methods, such as, for example, magnesium wires connected to an electric spark source, and leading into the interior of the package. Within the term metal foil, the term foil as used in this invention comprises rolled sheets of approximately .04-.00015" thickness. The thicker foil is specifically useful in providing fuel packages for larger rocket engines where a considerable weight has to be mechanically contained. The term metal comprises the base metal and its alloys, e.g. aluminum base alloys strengthened by 2-7% Mg or Mg, Cu, and Zn combined as in the known wrought alloy 7075. Thicker and thinner foil may be used combined, preferably disposing relatively few thicker layers, e.g. .04" thick to carry the mechanical load and to impart structural strength to a package, while a much larger quantity of thinner layers, e.g. .00035" thick, is interleaved with oxidant between each layer, providing a high degree of distribution of the combustible material. The use of thicker leaves between thinner ones allows also the use of aluminum alloy for the thicker leaves, e.g. containing up to 10% Mg or Zn, which alloys ignite more easily than relatively pure aluminum; however, such alloys are economically impractical to be rolled out to very thin gauges.

The use of aluminum foil within the contemplation of this invention is to be distinguished from that of actinically reactive metal foils of a thickness of 10 microns or less in flashbulbs, such as are described, for example, in U.S. Patent 2,611,255. Flashbulb compositions are designed to yield maximum actinic ray emission. Solid fuel composites and packages, such as the novel package of the present invention, involve wholly different principles and objectives, and are designed to possess characteristics leading to maximum development of high energy

upon burning within a confined space such as a rocket or ramjet engine.

The metal foil, such as aluminum foil, as used in accordance with this invention, performs both mechanical and fuel functions. Thus it serves simultaneously as a wrapping material and a combustible material. In this connection, the foil may be provided with perforations to aid in combustion, or with corrugations, quilting effects and the like to aid in providing space for disposing oxidant in a mechanically convenient way.

Quilted and sealed flat packages, similar to the familiar packaging of foods in sealed foil, are especially valuable for providing individually separated units of confined fuel materials. In a modified application of this principle, separate packages, like soup bags, are prepared and are loaded into rockets, to be burned one after the other. They are made up either in square or round or any other suitable shape to fit the inside shape of the fuel compartment. In the case of artillery rockets, such units are preferably used for desired variations of the range, thus not limiting one type of rocket for a definite range, but controlling the range by applying more or less units of prepackaged fuel containers. Such packages are not limited to the preferred metallic fuel only but may also contain additives of explosive fuels like gun powder or nitroglycerin or other organic fuels, like Thiokol, mixed with oxidants.

Such packages also may include liquids such as water, hydrogen peroxide, jet fuel or kerosene or any other liquid that serves as a fuel component which does not chemically attack the aluminum foil or sheet.

In another embodiment of this invention, aluminum foil may be employed for the aforementioned purposes in the form of laminations to paper or other cellulosic material, or to synthetic films, such as, for example, polyethylene, polystyrene, and the like. The laminating may be carried out using hydrocarbon materials such as wax, which possess fuel value. Where paper is used the paper may be impregnated with hydrocarbon fuel materials. In such laminations, the aluminum foil may be of any desired thickness, ranging preferably from about 0.0002 to 0.00035 inch in thickness, up to .0025 inch or even higher.

In another embodiment, an auxiliary fuel, such as a metal powder or grain, or hydrocarbon, may be disposed between the alternate layers of the aluminum foil. A suitable organic binder, such as a natural or synthetic rubber, or a synthetic resin, may also be incorporated with the auxiliary fuel, or employed to seal the edges of the fuel package.

Where an aluminous metal is used as an auxiliary fuel component, the aluminum may be in the form of powder or of granular aluminous metals, including aluminum or its alloys, such as alloys with magnesium. The aluminum or its alloys in the form of grained particles, possessing an oblong or needle-like shape, and produced by casting methods, have been found to possess unique and valuable properties as fuel components of solid composite rocket and ramjet propellants. Aluminum and its alloys having these physical characteristics may be prepared by a process which comprises essentially pouring the molten aluminum or aluminum alloy into a steel cup having the side wall perforated with holes of a predetermined diameter to impart the desired particle size, and rotating the steel cup at fairly high speed, whereby to expel the molten metal through the holes. In being thus centrifugally projected from the cup, the metal is rapidly cooled and assumes the structural characteristics of cast metal, as well as the oblong or needle-like shape mentioned. Such cast particles are advantageously of an average mesh size of about 20 to 100 mesh. It is also advantageous that not less than about 80 percent by weight of the particles possess a longest dimension at least five times the average of the other two dimensions.

The following examples illustrate various embodiments

of the invention, but it is to be understood that the invention is not to be considered as limited thereto.

Example 1

5 A fuel package was prepared from 15 sheets of Alloy No. 1235-O aluminum foil sheets 0.00025 inch thick (21 grams) with approximately 7 grams of ammonium perchlorate oxidant per sheet, sprinkled between the sheets. The package was rolled with a magnesium ribbon strip in the center, a small amount of gunpowder to serve as an igniter, and the edges sealed with rubber cement. The gunpowder was ignited, and the package burned rapidly.

Example 2

15 Corrugated 0.008 inch slick aluminum foil was prepared using corrugated paper board as a die, so that an area of approximately 2 sq. ft. (24"x12") was obtained. The corrugated interstices of the aluminum were packed with a mixture of 2 pounds of ammonium perchlorate and 1 pint of a solution of acrylonitrile rubber in toluene, and sheets of 0.0007" foil placed on each side of the corrugated sheet, and the assembly rolled around an aluminum rod as mandrel. The rod was withdrawn and the interior charged with gunpowder igniter. On ignition the roll burned satisfactorily and vigorously and completely in 15 seconds.

Example 3

30 15 sheets of grade 8-T-88 tissue paper, size 13.5" x 9.25" were arranged alternately between 15 sheets of aluminum foil 0.00025" thickness, of the same size, and ammonium perchlorate oxidant was sprinkled between each layer of foil and paper alternately, using approximately 1.5 grams of oxidant per each sheet of paper and 1.5 grams per each sheet of foil. The composite was rolled around a 1/2" aluminum rod, which was then withdrawn. A charge of gunpowder actuated by a heated Nichrome wire, energized by a six-volt storage battery, was used as igniter. Ignition was satisfactory and the package burned completely in 20 seconds.

Example 4

45 A fuel package was prepared using a 10 gram sheet of Alloy No. 1145-F aluminum foil 0.0025" thick. A mixture was prepared of 10 grams of cast aluminum-magnesium alloy grains, containing 20% magnesium, and 56 grams of ammonium perchlorate. This fuel mixture was placed on the foil and the foil was rolled into a spirally coiled cylinder, which was placed on asbestos inside a 3" diameter extruded aluminum pipe and ignited by means of a 1" Nichrome wire. Ignition took place immediately, burning was intense and vigorous, and the package burned completely in 50 seconds.

Example 5

55 92 grams of Alloy No. 1145-F aluminum foil, 0.0025" thick, and 10.5 inches wide and 7 feet long was corrugated so that channels about 1/2" x 1/2" extending across the width were made. 92 grams of 7075 aluminum alloy modified to contain 24% magnesium and cast in the form of grains having an approximate size to pass 80 mesh, were thoroughly mixed with 1 1/4 lbs. ammonium perchlorate oxidant and spread as evenly as possible in the corrugated channels. The composite was rolled into a 2.5" outside diameter by 10.5" long cylinder. The end of the cylinder was packed with a mixture of 20 grams of 7075 24% magnesium cast grains, having an approximate size to pass 80 mesh and 60 grams ammonium perchlorate, and a 1" length of Nichrome wire energized by a six volt storage battery served as a primary igniter. The package ignited immediately and exhibited intense and vigorous burning, burning time 1 minute, 12 seconds.

Example 6

75 93 grams of aluminum foil 0.00025" thick, 9 1/4" wide

and approximately 75 feet long was cut into 15 foot lengths, providing 5 equal lengths of foil, which were placed atop each other, disposing oxidant between each layer. A mixture of 93 grams of 7075 aluminum alloy modified to contain 20% magnesium and cast in the form of grains having an approximate size to pass 80 mesh, and 558 grams of ammonium perchlorate was placed evenly on the 15 foot lengths of foil. The composite was coiled into a 2.5" diameter x 9/4" cylinder, and the end of the cylinder packed with ammonium perchlorate and some of said alloy grains as a secondary igniter. The package ignited readily and burned extremely vigorously in 48 seconds.

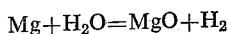
Example 7

Commercially produced atomized aluminum powder of -325 mesh is mixed with finely powdered NH_4ClO_4 in a ratio of 1 part aluminum powder to 2 parts of oxidant by weight. The free flow apparent density is 1.1-1.3 gr./ccm. A quart can is filled with this mixture without any compacting, thus maintaining the low density. It is ignited in the same way as in the other examples. After an initial burning time of 2-3 seconds, the whole mass detonates.

The same quantity of the mixture is then loosely disposed evenly in sandwich style between 20 leaves of aluminum foil of .0005" thickness, adding more NH_4ClO_4 between the leaves in a relation of 3 parts NH_4ClO_4 for 1 part of foil in weight. This package then is ignited at the layer between the two uppermost foil layers. The package burns evenly down in 23 seconds time without any detonation.

Example 8

The same package is prepared as described in Example 4 with the only modification, that the 56 grams of ammonium perchlorate is humidified in a humidity cabinet absorbing about 5% of its weight H_2O . As a result, a larger evolution of gaseous products is observed, presumably consisting substantially of hydrogen, formed by the reaction:



Example 9

The same package is prepared as described in Example 4, with the modification of adding 10 grams of H_2O_2 to the ammonium perchlorate, mixing it to a semi-solid paste, and then proceeding as described.

Example 10

The same package is prepared as described in Example 4 with the modification that 5 grams of gasoline are mixed with 66 grams of ammonium perchlorate to a semi-solid pasty condition and then processed as described. The result is a larger amount of gaseous products of combustion.

A difficulty analogous to the one discussed in Example 7 prevails in the case of rocket fuels consisting of solid mixtures of organic combustibles and solid oxidants, e.g. polymerized $\text{C}_2\text{H}_4\text{S}_4$, the approximate formula of the polysulphide polymer "Thiokol" of Thiokol Corp. of Trenton, New Jersey. Reference is made to an article in the magazine "Missiles and Rockets," March 1958, page 136, which shows that hidden pockets and cavities within such solid fuel mixtures can result in uneven burning characteristics. According to this invention, unit quantities of such fuels as "Thiokol" plus NH_4ClO_4 are interleaved with metal foil, preferably aluminum foil, with the result that uneven propagation of burning is hindered to a very considerable degree, thus rendering the use of such solid fuels much more reliable than heretofore and

effectively controlling the rate of combustion throughout the fuel composite.

While present preferred embodiments and practices of the invention have been described, it will be understood that the invention is not limited thereto, but may be otherwise variously embodied and practiced within the scope of the following claims.

What is claimed is:

1. A fuel package consisting essentially of an assembly of at least two layers of flat metal foil, said metal being selected from the group consisting of aluminum and magnesium, and a solid perchlorate oxidant for said metal foil loosely disposed and substantially enclosed between alternate metal foil layers, said package having sealed edges.

2. A fuel package consisting essentially of an assembly of at least two layers of flat metal foil, said metal being selected from the group consisting of aluminum and magnesium, a combustible particulate metal fuel including a member selected from the group consisting of aluminum and alloys of aluminum and magnesium, and a solid perchlorate oxidant loosely disposed and substantially enclosed between alternate metal foil layers, said package having sealed edges.

3. A fuel package consisting essentially of an assembly of at least two layers of flat metal foil, said metal being selected from the group consisting of aluminum and magnesium, said layers of metal foil being coiled into the form of a roll, and a solid perchlorate oxidant for said metal foil loosely disposed and substantially enclosed between alternate metal foil layers, the ends of said package being sealed with aluminum discs.

4. A fuel package consisting essentially of an assembly of at least two layers of flat metal foil, said metal being selected from the group consisting of aluminum and magnesium, said metal layers being coiled into the form of a roll, a combustible particulate metal fuel including a member selected from the group consisting of aluminum and alloys of aluminum and magnesium, and a solid perchlorate oxidant loosely disposed and substantially enclosed between alternate metal foil layers, the ends of said package being sealed with aluminum discs.

5. The package of claim 2 in which the particulate metal fuel is a granular aluminum-magnesium alloy.

6. The package of claim 4 in which the particulate metal fuel is a granular aluminum-magnesium alloy.

7. The package of claim 1 in which the metal foil is rolled aluminum foil having a thickness between about 0.04 and 0.00015 inch.

8. The package of claim 1 in which the innermost metal layers are aluminum foil having a thickness of about 0.00035 inch, and the outermost metal foil layers are aluminum foil having a thickness of about 0.04 inch.

9. The package of claim 3 in which an ignition means comprising a magnesium wire extends from the interior to the exterior of said package.

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