HANDBOOK OF PYROTECHNICS

by

Karl O. Brauer

HANDBOOK OF PYROTECHNICS

by
Karl O. Brauer

1974
CHEMICAL PUBLISHING CO. INC.
NEW YORK, N.Y.

Printed in the United States of America

Introduction

During the last twenty years, the field of pyrotechnics, which was limited mainly to applications in military ordnance, fireworks, and rock blasting, has been developed to a highly advanced science and to a widely used technology. Today, pyrotechnics find extensive applications in spacecraft, aircraft and underwater vehicle systems, and also in production methods, for example for metal forming, cladding, and riveting.

Pyrotechnics are ideally utilized in applications where space is limited and where low weight is a major requirement, as for instance in aircraft crew ejection systems, or in external fuel tank release mechanisms. Optimum utilization of the small size, low weight and high reliability of pyrotechnics is made in spacecraft and missile applications. Many space missions would be impossible without pyrotechnic devices and pyrotechnic systems. Escape tower release, stage separation, fairing release, recovery and landing systems, location aids, and flotation systems are some typical examples of ideal utilization of pyrotechnics in spacecraft. Pyrotechnic devices are widely used in missile systems for ignition, control, booster separation, fairing release, and, in cases of malfunction, for destruction.

"Pyrotechnic" means "explosive-actuated" and refers especially to devices in which explosives are burned rather than detonated. In aerospace applications, all electrically fired explosive devices are referred to as "electro-explosive".

The main advantages of pyrotechnic devices are: High power-to-weight ratio, high reliability, small size, low operating current, simple circuit requirement, reasonably low cost, ability to deliver more energy in a shorter time than any other mechanical device, and precisely controllable force.

Another advantageous feature of some pyrotechnic devices is the possibility of providing time delays by placing elements with fixed burning times between sections of fuze, or by mounting time delay trains in the explosive devices themselves.

In recent years, it was difficult for engineers, technicians, designers and students to solve some problems connected with the design, development, testing and evaluation of pyrotechnic devices and systems because of lack of sufficient data, design rules, and experience. Sparse data about some explosive materials and only a few reports about the performance and reliability of a certain type of squibs and power cartridges were available. As a result of this lack of sufficient data, until a few years ago, a newly developed pyrotechnic device could only be qualified by a very extensive and costly series of tests to warrant reliable functioning. The author, who was instrumental in the development and design of several well-known revolutionary aircraft, missiles, spacecraft and underwater vehicles in Europe and in the United States, for example the first multi-engine turbojet aircraft, the first tactical transport aircraft Ar 232, the first turbojet bomber of the world, Ar 234, the Dolphin and Polaris missiles, drones, aircraft crew ejection systems, Paraglider systems, recovery and landing systems for the Gemini and Apollo spacecraft and instrument capsules, re-entry vehicles, and underwater vehicle systems, experienced this lack of design guides and data for the development and design of pyrotechnic devices and systems for many years.

It is the purpose of this handbook to provide useful data and information about theory and practical application of pyrotechnics for engineers, designers, technicians and students. The contents of this handbook are divided into six parts: Explosive Materials, Explosive-Actuated Devices, Pyrotechnic Systems, Reliability and Testing, Explosive Production Methods, and Appendix.

The handbook contains numerous charts, graphs and illustrations as useful aids. Theory, data, and practical applications are explained in detail. Valuable new information is presented in this handbook, as for example data about the effects of extreme environmental conditions on pyrotechnic materials and devices, hints and data for qualification testing, hints for the design and application of pyrotechnic systems, and data for the application of explosive methods in manufacturing processes.

It is recommended to use this handbook together with the book

"Military and Civilian Pyrotechnics" by Dr. Herbert Ellern, published by the Chemical Publishing Company, which contains more detailed information about the properties and production of pyrotechnic materials and an extensive manufacturing formulary.

In writing this handbook, the author made an attempt to cover the whole field of pyrotechnics technology and to present the newest and most complete data and information. The author would appreciate comments from users of this book, which may help to improve the contents of future editions of this handbook.

Thousand Oaks, California
Karl O. Brauer

Contents

Part I

Explosive Materials

Explosive materials and compositions which are commonly used in pyrotechnic devices and systems are described in detail in the present Part I, Chapter 1 and 2, to provide the necessary information about the functioning, application, and physical and chemical properties of these materials. Only with the knowledge of the basic characteristics of these materials will it be possible for the user of this handbook to fully understand the functioning of pyrotechnics and to develop new pyrotechnic devices and systems.

1 Explosives and Compositions

Explosive materials and compositions are used in a great variety of pyrotechnic devices and systems mainly as producers of either gas, flame, heat, shock, smoke, light, or sound. Since explosives usually release energy in the form of heat and gas due to chemical disassociation in a way similar to gasoline, kerosene, butane, oil, and coal, they can generally be classified as fuels. The main difference of explosives as compared with conventional fuels is the characteristic that explosives contain oxygen and do not require atmospheric oxygen for combustion, and that the combustion rate of explosives is much faster than that of conventional fuels. The ability of explosives to perform work is based on the release of gas at high temperature and at high pressure. In most explosives, this pressure effect is aided by the quickness of the action which often may produce shock phenomena.

Explosive and pyrotechnic materials and compositions are classified, according to their characteristics, into two major categories:

A. Deflagrating or burning materials and compositions, which undergo combustion,

B. High explosives, which undergo detonation or high-order explosion, to differentiate it from low-order explosion, such as fast combustion of propellant.

All explosives, primers, propellants, and high explosives, are unstable materials by their very nature. While they are safe to handle and to process under controlled conditions, they must be treated and handled with great caution and the respect that their latent power deserves.

It is a not commonly known characteristic of some explosive materials that, the more powerful the explosive, the more difficult it is to initiate. This feature is the main reason for the arrangement of a minimum of two elements of explosive materials in an explosive train, in which the first material is a priming explosive to provide a reliable initiation of the second charge, which is the main charge, often also called base charge, and which has a high power output for performing the required work. The priming explosive is often also called "ignition bead" which, in many pyrotechnic devices, consists of a very small quantity of a highly sensitive explosive material and which is applied to the electric bridgewire in the device to be initiated by heat.

In some devices, a third or intermediate charge is used to aid in the transition to detonation. In these cases, initiating explosive materials are used for the ignition bead and for the intermediate charge, whereas a booster material is used for the main charge.

According to this commonly used arrangement of different explosive elements, high explosive materials can also be classified into the two major groups: Initiating or primary explosives and non-initiating or secondary explosives.

1. Initiating explosive materials which are initiated by an electric current, impact, or friction, are used to initiate the detonation of relatively insensitive explosive materials.
2. Non-initiating explosive materials are detonated by an initiating material which, during the detonation, generates the required shock to accomplish the necessary destruction for the actuation of the pyrotechnic device. Non-initiating explosives can be divided into three types:
   a. Boosters which can easily be initiated and which detonate at a high rate. For this reason, booster materials are not recommended for loading in large masses. A typical booster material is lead azide.
   b. Bursting charges which are initiated by a booster and which are suitable for loading in mass. A typical bursting charge material is TNT.
   c. Explosive materials which can only be used as ingredients in explosive mixtures, because they are either too sensitive or too insensitive to be used alone. A typical example for a too sensitive explosive material is nitroglycerin, and a typical example for a too insensitive explosive is ammonium nitrate.

A. *Priming Materials.*

Priming or "first fire" materials are the first explosive material initiated in an explosive train and are used to initiate the detonation of less sensitive high explosives. Only a few explosives which have a high degree of sensitivity to initiation through shock, friction, electric spark, or high temperature, but which are not too sensitive, are suitable as ideal priming explosives. They must be able to release very high temperature or shock, or both, upon disassociation. A high sensitivity of priming materials is necessary because they are usually initiated either by raising their temperature by means of an electrically heated wire, or by the spit of a powder fuse, or by shock caused by the striking of the explosive by a firing pin in a rifle or pistol cartridge or in a special mechanically-initiated device. It is the main function of primers, which are power producers, to initiate a second, more stable and better power generating explosive which requires the high temperature output from the priming explosive.

Typical commonly used priming explosive materials are:

Lead azide
Lead styphnate (lead trinitroresorcinate)
LMNR (lead mononitroresorcinate)
KDNBF (potassium dinitrobenzofurozan)
Barium styphnate
Zirconium potassium perchlorate

Other priming materials which are not frequently used are mercury azide, potassium chlorate, and mercury fulminate.

B. *Propellants*

Deflagrating material is divided into three groups, according to their physical shape:

1. Loose powders, fine grains, spherical shotgun grains
2. Pressed or extruded grains (size 1/4 inch or larger)
3. Solid propellant billets, as used in gas generators

Deflagrating materials are generally good gas or heat producers. Some of these materials burn in the same manner as solid rocket propellants, but more rapidly. Since deflagrating materials are more stable than primers, they are usually set off by an initiating material. The force exerted by the deflagrating material is produced by the vapors evolved during combustion, in the same manner as in a solid-propellant auxiliary power unit (APU) gas generator. Similar to the conventional solid propellants, they burn evenly over their whole exposed surface area. Their burning rate depends mainly on the physical form of the deflagrating material. The highest burning rate is obtained in a charge consisting of thin flakes. The pressure rise rate decreases with an increase of the grain size of the material, and the burning rate is also affected by temperature and pressure.

Deflagrating powders, or propellant or pyrotechnic powders are used as the main charge in numerous impulse-type pressure cartridges which are utilized for the actuation of valves, thrusters, and guillotine devices. Important factors that influence the selection and sizing of the propellant powder for a certain application are: Maximum energy required, ignitibility, peak pressure, and burning time. The time from ignition of the propellant to its total combustion depends on the chemical composition of the propellant and the shape or form factor, and on the temperature and pressure. Very important for proper sizing of a propellant charge of a given shape for a certain required output and burning time is the ratio between surface area and total volume, since propellant powders burn only on the surface. When a very fast burning rate and a very high peak pressure is required, flake or flat powders are ideally used, whereas spherical or cylindrical powders are best used when a lower pressure for a longer period of time is required.

Rifle-type powders have such a fast burning rate and develop such a high pressure that the total combustion time may be only one millisecond. In applications where burning times of one second or longer are desirable, it is not advisable to use pressure cartridges with rifle-type smokeless powder which has a too fast reaction time, but to use a gas generator propellant instead. The propellant normally used in gas generators, which is similar to the propellant used in rocket engines, has a much slower burning rate than smokeless powder. The propellant used in a typical gas generator may have a burning rate of 0.1 inch per second at a pressure of 2000 psi, whereas the burning rates of smokeless powders are measured in inches per second. For this reason, the gas generator propellant can ideally be used in applications where burning times of many seconds are required. Gas generator propellants are more difficult to ignite than smokeless powders, and some of these propellants require relatively high pressures and temperatures to be maintained in order to sustain combustion.

Other typical burning explosives are $BKNO_3$, double-base powders, Hi-Temp (RDX), and zirconium potassium perchlorate.

C. *High Explosives*

High explosives are chemical compositions, which when initiated by a suitable stimulus, disassociate almost instantaneously into other more stable components. This reaction is known as high-order or low-order detonation. As a result of the explosive decomposition, detonating explosives produce some gas and high temperatures. The detonation is so fast that a shock wave is generated that acts on its surroundings with great brisance, or shattering effect, before the pressure of the exerted gas can take effect. This type of explosive material is used to pulverize rock and to sever steel beams. The most sensitive detonating explosives are so unstable that they can be set off by the slightest vibration, friction, or heating, and for this reason, such type of detonating materials is useless.

A different type of detonating explosive, which is relatively stable, is used in explosive devices and systems. Some of these high explosives are so stable that rifle bullets can be fired through them or they can be set on fire without detonating. They are set off only by the severe shock of an initial detonation, which is usually supplied by the explosion of a more sensitive explosive material. The more stable explosives which detonate at very high velocities of up to 9000 meters per second exert a much greater force during their detonation that the explosive materials used to initiate them.

Typical high explosives which are widely used in explosive devices are Tetryl, TNT, RDX, and PETN. For the initiation of the most commonly used materials, RDX and PETN, a shock impact of 3000 to 5000 meters per second is required which can be obtained only from another explosive material. For this reason, explosive devices in which RDX or PETN is used as a main charge, contain an explosive train consisting of three units: a primer, a booster, and the high explosive main charge. An exception are EBW (explosive bridgewire) devices, where RDX and PETN is directly initiated by the bridgewire.

The following example may explain the tremendous shock generated by a typical high explosive: If an explosive charge of lead azide is set off against one end of a three foot long and one foot diameter cylinder consisting of RDX, the shock from the dis-