Studies on the Use of Epoxy Resin Binder in Small Rockets

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ABSTRACT

A propellant suitable for use in small firework rockets has been developed. The binder used in the composition is an epoxy resin. The composition can be mixed while wet, thus reducing safety hazards. The propellant has been evaluated using a simple lab-built thrust measurement apparatus, and has been shown to have superior performance to Black Powder.

Keywords: rocket, epoxy, thrust measurement

Introduction

The production of pyrotechnic mixtures is an inherently dangerous process, due to the possibility of a rapid violent highly exothermic reaction occurring. Several factors affect the probability of initiation of such a reaction. Examples of such factors are particle size and shape of the components, the possibility of electrostatic spark generation and the presence of moisture. Jennings-White and Kosanke[1] have outlined the hazards of some specific chemical combinations, and the pyrotechnic literature is filled with examples and good advice on how to avoid accidents.[2–6]

Most production processes are still carried out by hand and are therefore good candidates for mechanisation. The majority of pyrotechnic mixtures require dry powder mixing at some point during the production process. Such mixtures are sensitive to initiation from several sources, such as friction and electrostatic spark. The inclusion of a liquid component to pyrotechnic mixtures would greatly reduce these hazards and would also facilitate automation of the production process.

Many large rocket systems use a polymer, such as hydroxy-terminated polybutadiene (HTPB), as a fuel/binder component.[7,8] The production of the propellant grains is by an extrusion process.[7] The main objective of the work described in this paper was to find an extrudable composition that would work in small firework rocket motors.

A suitable binder for use in such compositions would need to have several desirable properties. It would need to burn well in order to maintain the high reaction rate required in small rocket motors. It would need to be easily processable, which would restrict the choice to thermosetting resins. Compositions containing thermoplastic resin binders would need to be heated during the mixing stage, which is undesirable for safety reasons. Thermosetting resins can be processed at low temperatures, and then cured at relatively low temperatures. The candidate binder should retain good mobility at high solids loading, and it should have excellent dimensional stability on curing. This demanding range of properties should also be available in a polymer that is economically attractive.

Most commercially available thermoplastic materials have relatively high melting temperatures and were considered to be poorly suited to the requirements outlined above. Thermosetting resins tend to have better dimensional stability than thermoplastics, and this makes them attractive for use as a pyrotechnic binder. They are changed irreversibly during the curing process from flowable products into highly intractable cross-linked resins. Examples are phenol-formaldehyde resins, such as Bakelite™, and epoxy resins, such as Araldite™. Both types of resin have been used in large items.[9,10]

Experimental

Epoxy resins were selected for use in rocket motors after it was found that phenol-formaldehyde (PF) resins were not suitable. It was found that a significant percentage (approximately 20%) of rockets made using a PF resin exploded shortly after ignition. This was attributed to the presence of voids in the composition, arising from the curing of the PF resin. The curing process produces water, which evaporates and leaves voids behind. Such a situation is catastrophic for any rocket motor and cannot be easily overcome using this PF resin system.

Epoxy resins undergo a crosslinking process, but no condensation products are formed and so the formation of voids should not occur. The chemistry of the formation of the resin is adequately described in most polymer chemistry textbooks; so will not be described here.

A propellant composition was developed that used potassium perchlorate as the main oxidiser component. Potassium benzoate and charcoal were used as the fuel components in a 2:1 ratio. The composition was arrived at by development of a whistling composition. Copper(II) oxide was incorporated into the mixture as a burn rate enhancer. Transition metal oxides are known to facilitate the decomposition of perchlorates,[11,1b] and CuO was selected to be used. Manganese(IV) oxide, nickel(II) oxide and iron(III) oxide were evaluated, but none performed as well as CuO. The composition is given in Table 1.

Table 1. Composition of Rocket Propellant.

Component	Amount in parts	Amount in %
Potassium perchlorate	75.0	72.7
Copper(II) oxide	1.4	1.4
Potassium benzoate	11.2	10.9
Charcoal	5.6	5.4
Epoxy resin	9.9	9.6

The solid components all passed a 125-mesh sieve. The charcoal used was 60-dust grade (particle size of 60 microns to dust).

The resin used was Araldite 219, supplied by Ciba-Geigy Ltd. This consists of a bisphenol-A epichlorohydrin prepolymer and a modified aromatic amine hardener.[12] If desired, a carboxylic acid may be added to accelerate the hardening process, as the acid catalyses the epoxy ring opening step. A small amount of acid (about 1% of the resin component by weight) was used to speed the curing process.

The solid components were sieved separately. The oxidiser components were then added to the resin and mixed thoroughly. The remaining ingredients were then added to this mixture. This produced a fairly stiff material, which was extrudable. The mixture was piston-extruded into the motors, a PTFE coated gallery spike was inserted and the motors were cured at 50 °C for 3 hours. The spike was then removed. The motors were made of rolled cardboard, twitched at one end to form a nozzle. The length of the tube was 90 mm, o.d. = 17 mm, i.d. = 12 mm, nozzle diameter = 4 mm. The spikes used had variable length, but all had a base diameter of 3 mm tapering to 2 mm at the top. The nozzle was positioned 14 mm from the end of the tube. The mass of composition used in each motor was kept as constant as possible, at 10 ± 1 g.

Other epoxy resins were tested for use in rockets, but none performed as well as 219 resin. Those evaluated were 751C (normal prepolymer + polyoxypropylenetriamine hardener), 672C (normal prepolymer + isophorone diamine + benzyl alcohol) and RX710C (prepolymer contains bisphenol-F).

The rockets were evaluated qualitatively using visual trials, but quantitative evaluation was available by using a simple home-built thrust meter. This apparatus has been more fully described elsewhere,[13] but essentially it consists of an adapted strain gauge. Thrust data can be obtained easily, which is very useful for comparison and development purposes. However, visual tests are still an important part of evaluation due to the visual nature of the pyrotechnic art!

Table 2. Effect of Different Burn Rate Catalysts on Thrust.

Material	Thrust in g	(lb.)	Normalised (CuO = 100)
Copper(II) oxide	1270	(2.80)	100
Manganese(IV) oxide	1080	(2.38)	85.0
Nickel(II) oxide	1080	(2.38)	85.0
Iron(III) oxide	630	(1.39)	49.6

Results and Discussion

Figure 1 is a trace of a small rocket (dimensions given in previous section) filled with the composition detailed in Table 1. A Black Powder model gave a similar trace, with a peak height of approximately 750 g (1.65 lb). It can be seen that the epoxy-bound composition develops a considerably higher thrust than the Black Powder model. It is noteworthy that the peak thrust is developed less than half a second after ignition, and does not last for more than 0.3 s.

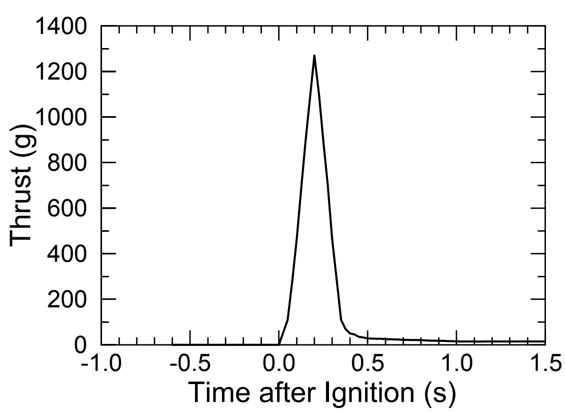

Figure 1. Thrust trace for epoxy-bound composition.

Visual tests showed that the epoxy-bound composition powered the motor to a greater height than the Black Powder. Both motors were filled using the same mass of powder, and contained the same gallery length. During the launch phase, several different observers noted that the epoxy-bound composition seemed to produce more "zip" than the Black Powder motors.

Table 2 contains data on the peak thrust obtained from compositions containing different burn rate catalysts. The compositions were the same as in Table 1, except that copper(II) oxide was replaced by the materials listed.

The length of the gallery spike also plays a large role in the burning of the propellant. (Figure 2 shows the design of a typical small rocket motor.) The dependence of thrust upon gallery length is given in Figure 3.

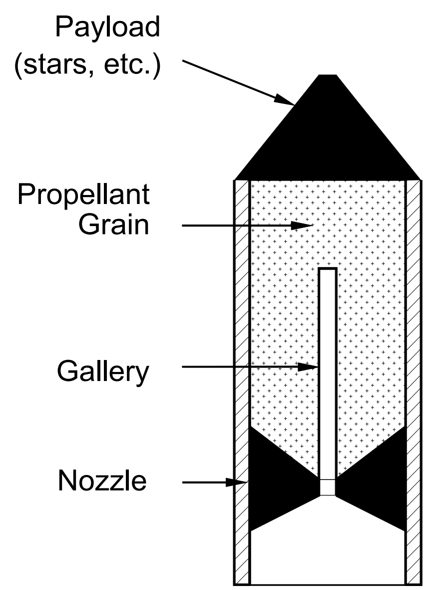

Figure 2. Design of a typical small rocket motor.

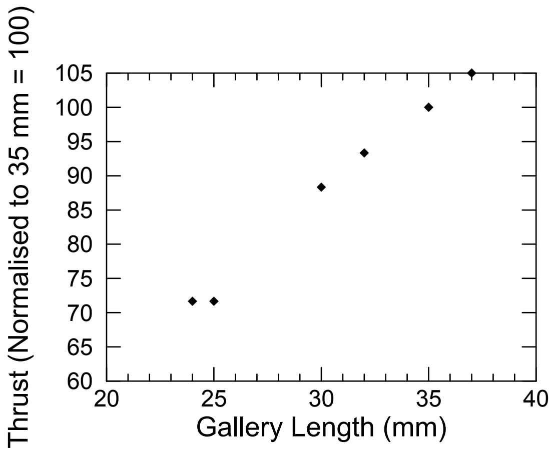

Figure 3. Effect of gallery length on thrust.

The data in Figure 3 has been normalised to 35 mm = 100. Although thrust increases as the gallery length increases due to an increase in surface area, the time of burn drops. "Burn through" is more likely with longer gallery lengths, and so 35 mm was set as a standard gallery length around which to optimise the composition.

Conclusion

An epoxy-bound propellant for small firework rocket motors has been developed, and has been shown to have superior performance to Black Powder. The composition can be mixed wet, which significantly reduces the risk of accidental ignition.

Acknowledgements

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