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Cook-Off Study of Combustible Cartridge Cases

R.K. Syal and P.S. Narr

Explosives Research & Development Laboratory, Pune–411 021

ABSTRACT

Combustible cartridge case (CCC) offers specific advantages over the conventional metallic (brass) case. The CCCs are made of cellulose fibres with suitable explosives to ensure debris-free combustion inside the gun barrel. The presence of explosives in CCC, however, causes increased vulnerability to cook-off. An experimental study of cook-off of CCC was carried out by hot plate technique. Cook-off data for CCC of different compositions and with various cook-off delay coatings was measured. It was found that out of four types of coatings, two gave better results.

1. INTRODUCTION

Combustible cartridge cases (CCCs) for tank/artillery gun ammunition are being introduced all over the world, because of their definite advantages over brass cartridge cases. There has been, however considerable demand in improving their mechanical and combustion properties to ensure proper performance under different environmental conditions.

When a CCC is inserted in a hot gun chamber and allowed to remain there for some time, it can result in automatic ignition of CCC/propellant which is termed as cook-off. Thus, cook-off may be defined as an unintended ignition of a CCC as a result of heat transfer from overheated barrel or gun chamber to CCC. In the case of conventional ammunition, a part of the heat is dissipated outside due to the heat capacity of the metallic material (brass) while in a CCC a more rapid cook-off is expected because of the absence of the metallic case.

Cook-off is regarded as a highly undesirable event. If it occurs with the breech open, the gun crew becomes vulnerable to severe flash and blast. If the breech is closed, cook-off may not only cause injury to the crew, but may also result in severe damage due to unpredictable projectile range/accuracy. Thus, from a safety point of view, it is very essential to determine the cook-off characteristics of the ammunition.

The development of CCC ammunition is a new field and hence no substantial data is currently available in open literature[1]. However, studies on cook-off behaviour of propellants in a conventional cartridge case (brass) have been duly reported[2].

The cook-off studies of CCC will be helpful not only in understanding and modifying its composition and nature of coating but also the mechanism of cook-off ignition reaction. This will also facilitate the design of better ammunition and stowage system in armoured vehicles to prevent accidental cook-off of stored ammunition.

The cook-off is best studied by actual firing or heating the weapon to actual firing temperature. This procedure is time-consuming and costly. Alternatively, cook-off is measured by carefully controlled heating of the metallic block and measuring the time taken for the ignition of the sample at a set temperature[3,4].

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2. EXPERIMENTAL

2.1 Apparatus

A special apparatus was designed and used for cook-off study (Fig. 1). It consisted of a cylindrical aluminium block of 50 mm diameter and 75 mm length. A suitable heating element was wound in such a manner as to maintain a good temperature distribution at all points on the surface. Complete system was properly insulated. The top surface was kept open which acts as hot surface for conducting experiments.

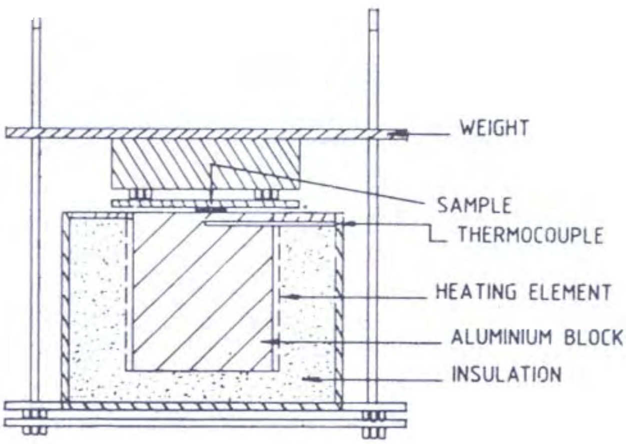

Figure 1. Schematic diagram of the apparatus used for cook-off study.

The temperature of the block was measured by platinum-rhodium thermocouple introduced into the aluminium block just 0.5 mm below its surface and up to the centre of the block. The top of the block was covered with an aluminium foil of 0.01 mm thickness to ensure a clean surface after every experiment. This prevented the formation of a carbonaceous residue which would otherwise act as an insulating layer between the sample and the aluminium block. The temperature of the block was controlled to ± 2 °C with the help of a Stanton-Redcroft universal temperature programmer. A 500 g weight was used as standard for achieving proper contact between the sample and the hot surface.

2.2 Sample Preparation

The choice of the CCC composition is mainly governed by ballistic parameters and mechanical properties. Considering the major requirements of tank gun ammunition, two compositions, viz, *C*1 and *C*2 were subjected to cook-off study (Table 1). To improve the cook-off behaviour of the CCC composition, certain heat inhibition coatings were used. These coating materials were compatible with the ammunition. Test pieces[5] of 100 × 30 × 3 mm dimension were prepared from the full CCC of composition *C*1. Only one side of a test piece was coated. Table 2 shows different coating materials used in the study. These test pieces were dried at a temperature of 60-65 °C till a constant weight was recorded. The pellets of 5 mm diameter were obtained by punching these test samples. Proper care was taken in removing loose particles, if any, from pellet surface. Any pellet found to be faulty was discarded.

Table 1 Composition of CCC

Ingredients	Composition	
	*C*1 (wt%)	*C*2 (wt%)
Nitrocellulose (12.6 N)	60	80
Picrite	20	
Cellulose	15	15
Dibutylphthalate	4	4
Diphenylamine	1	1

Table 2. Details of coating materials

Coating	Decomposing temperature (°C)	Nomenclature	Source
A	135	Copal varnish	Kanke Paints & Varnishes, Bombay
B	181	Garware paint (acrylic-based)	Garware Paints, Bombay
C	386	Polyvinyl formal (10% solution in toluene + alcohol)	Dr Beck & Co, Pune
D	275	Elastopolymer EP-4 (50% EP; 50% styrene; 1% accelerator & catalyst)	ERDL, Pune

2.3 Measuring Technique

The aluminium block was heated to the required temperature with the help of a universal temperature programmer which was programmed to 'hold' mode. The heating was done for 15 min to stabilize the temperature before the experiment was conducted. An aluminium foil was kept on the aluminium block and the coated side of the sample facing the foil was kept on the block. A weight (500 g) was lowered immediately on the top of the sample for proper contact and simultaneously a stop-watch was started. Time was measured till fumes started originating from the sample. An average time of 5 samples was recorded.

3. RESULTS AND DISCUSSION

The temperature of the gun barrel which is directly responsible for the cook-off is dependent on the weapon system, the type of ammunition and the rate of firing. The rise in temperature of the gun chamber can be controlled to a certain limit by the use of cooler propellant or by reducing the rate of firing. But, these means will directly affect the utility of the weapon system. Hence, the composition of CCC and the type of coating must provide the alternate solution to cook-off. The highest temperature (Tc) and time (t) to which CCC can be subjected without undergoing cook-off must be determined.

The time required for CCC to cook-off in the hot gun chamber is a function of temperature and is inversely proportional to the gun-chamber temperature. If T is the highest temperature reached in a weapon system, the relation can be expressed as $t \propto 1/T$ or $t = A(T)^{-B}$ where A and B are empirical constants which vary for different weapon systems; when $Tc > T$, cook-off will not occur.

Two compositions of CCC selected for this study were adjusted to ensure debris-free combustion of CCC in the gun, with reasonable mechanical properties. Out of various coating materials readily available, four were chosen after due screening in the laboratory by classical techniques.

The thermal inhibition coating can prevent cook-off in several ways: (i) by forming a barrier between the degraded substrates in air; (ii) by modifying the degradation reaction in such a way that water and carbon oxides are formed instead of combustible organic compounds; (iii) by evolving gases such as nitrogen or chlorine to dilute the concentration of oxygen in the immediate gas phase; and (iv) by producing halogen materials which can inhibit the flame propagation process.

The increase in the thickness of these coatings can prevent cook-off, but other problems are faced, such as unburnt pieces inside the gun chamber.

Reproducibility of tests are difficult as CCC is a heterogenous mixture and difficulties are further magnified when the tests are carried out on a coated substrate. Practical methods of application, such as brushing, cannot produce uniform film and the greater the area of the substrate, there is more likelihood that an area of greater or less than average film thickness is obtained. Thermal analysis of these coatings shows a slow decomposition, with the decomposition-temperature varying from 386 °C for PVF to 135 °C for copal varnish.

Table 3. Cook-off results

Surface condition		Temperature (°C)									
		200	205	210	215	220	225	230	235	240	245
		Cook-off time (s)									
$C1$ uncoated		≮ 300	80.8	37.0	21.8	11.6	9.6	5.3	3.8	2.3	1.1
$C2$ uncoated		≮ 300	≮ 500.0	103.6	45.9	30.5	18.2	13.4	11.4	8.1	5.0
$C1$ coated with A	(i)	≮ 300	74.3	47.5	27.2	16.4	10.4	5.8	2.9	2.4	1.4
	(ii)	≮ 300	55.0	40.8	25.6	11.6	7.1	4.8	3.3	2.4	1.5
$C1$ coated with B	(i)	≮ 300	53.4	40.6	26.8	16.6	11.1	7.2	5.4	3.3	2.5
	(ii)	≮ 300	57.2	39.2	27.0	17.6	12.5	8.9	6.6	4.9	4.0
$C1$ coated with C	(i)	≮ 300	76.5	42.9	23.5	13.6	10.6	7.0	4.7	3.1	1.7
	(ii)	≮ 300	104.3	42.3	30.1	16.6	13.2	8.1	7.5	4.6	3.0
$C1$ coated with D	(i)	≮ 300	53.0	31.6	21.7	13.4	9.7	7.4	5.0	3.8	2.4
	(ii)	≮ 300	63.3	40.3	25.9	17.3	12.2	8.6	7.6	4.7	3.1

(i) : 10 ml coating per 100 sq cm; (ii) : 20 ml coating per 100 sq cm.

It was observed that at 200 °C none of the samples undergo cook-off even after 5 min. This indicates that the substance is heated to the extent that the temperature distribution due to equilibrium between the rate of the heat generated by the chemical reaction and that of the heat removed is more or less maintained and the reaction, therefore, does not lead to accelerated gas phase stage.

Table 3 shows that at temperatures 205 °C and beyond, cook-off is observed in all the samples. This occurs when the heat released by a reaction has no time to be removed and spontaneous rise of the temperature takes place. In this phase, active pyrolysis begins where combustible gases from the substance evolve rapidly to support cook-off and it is spontaneous. Cook-off is always preceded by the formation of a small foam like mound of bubbling liquid around the sample and immediately followed by ignition of the sample.

Figure 2 shows that the composition *C*1 has less cook-off time as compared to the composition *C*2 because in the confined system, the decomposition of nitroguanidine commences[6] between 161 and 165 °C.

The coated samples produce encouraging results when acrylic-based paint coating is given, followed by elastopolymer and PVF (Figs 3 and 4).

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