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# Performance, mechanical and thermal properties of double base rocket propellant including copper oxide as burning rate modifier

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**Abstract:** In this work, different percentages of Copper oxide have been added to double base rocket propellant (DBRP) as burning rate modifier. A conventional DBRP has been prepared and studied for comparison. The mechanical properties at different temperatures were studied. The heat of combustion and ignition temperature of the samples were measured. The performance represented by the operating pressure and the burning rate were evaluated at 8mm throat diameters. The thermal behavior of the traditional DBRP in comparison with a selected composition containing copper oxide was discussed. It was concluded that the addition of copper oxide in DBRP has positive effect on the mechanical properties of the traditional DBRP while slight increase in the performance properties was observed.

**Keywords:** solid rocket propellant, copper oxide, performance, mechanical properties.

## 1. Introduction

Double base rocket propellants (DBRPs) are famously used for military applications. They contain mainly nitrocellulose (NC) and nitroglycerine (NG) [1, 2]. The combustion properties of DBRPs depend on the burning rate which is affected by the operating pressure [3]. DBRP includes additives to improve the ballistic properties, sensitivity and stability. In several applications, the plateau effect which is based on the independence of the burning rate on the pressure is required. In addition, the mesa effect is observed if the rate of burning decreases by the increase of the pressure [4, 5].

Recently, several publications studied the replacement of NG by advanced oxidizers to improve the safety and the stability of DBRP [6-8]. It was also stated that 2,2,2-Trinitroethyl-formate (TNEF) is an interesting oxidizer which might be used to replace NG in DBRP [8]. Actually, these new oxidizers are still in the research stage.

On the other side, several publications presented the effect of adding copper and lead salts of aliphatic acids on the plateau effects of DBRP. It has been reported that copper salts of aromatic acids are of significant influence on increasing the burning rates more than the lead salts [9]. The effect of Lead salts on the decomposition kinetics and the thermal stability of DBRP were studied using TGA



and DSC techniques. The decomposition temperature of catalyzed DBRP has lower value than the traditional DBRP [10, 11].

The influence of different ballistic modifiers on the combustion properties of DBRPs was investigated in literature [12,13]. The thermodynamic calculations obtained by applying the thermal techniques, present data about the influence of burning rate modifiers on the thermal behavior, rate of reaction and the mechanism of the reaction which could affect the ballistic performance properties of the DBRPs [14-16].

In this work, the addition of copper oxide to lead stearate as burning rate modifiers on the characteristics of DBRP was studied. The heat of combustion and the ignition temperature of the prepared samples were measured. The mechanical characteristics of the prepared compositions were determined at different temperatures. The DBRP performance was determined by measuring the operating pressure and the burning rates of the studied samples at different temperatures using 8mm throat diameter. In addition, the thermal behavior was studied using DSC technique.

## 2. Experimental work

### 2.1. Preparation of DBRP compositions

Four formulations of DBRP based mainly on NC and NG in addition to lead stearate and different percentages of copper oxide were prepared. The compositions mainly based on 57.7 % NC, 30 % NG, 5 % DNT, 2 % centralite I, 3 % DBP and 0.3 % carbon black. Table (1) includes the percentage of the burning rate modifiers in each composition. The compositions were prepared in batches (12 kg each) by the extrusion method [17]. The traditional DBRP (T-DB) and other compositions (DB-1, DB-2 and DB-3) were formulated as multi-tube grains.

**Table 1.** Weight percentages of copper oxide in each prepared composition

Sample	T-DB	DB-1	DB-2	DB-3
Copper oxide [%]	0.0	0.3	0.4	0.5
Lead stearate [%]	2.0	1.7	1.6	1.5

### 2.2. Ignition temperature determination

Julius Peter's apparatus was used to determine the ignition temperature of the compositions [18]. The measurement is based on placing the samples in test tubes and inserted them into the heating block. A uniform 5 °C min<sup>-1</sup> heating rate was used to detect the ignition point of the studied compositions. The results are presented in table 2.

### 2.3. Heat of combustion determination

A calorimeter model PARR 6200 was used for measuring the heat of combustion of the prepared compositions. The samples were inserted in the bomb and kept in touch with a platinum wire followed by filling the bomb by excess of oxygen (20 atm) in order to be sure from the complete combustion of the compositions. Increasing of the temperature inside the calorimetric vessel was reported and the heat of combustion was calculated and written in table 2.

### 2.4. Mechanical properties determination

The maximum stress ( $\sigma_m$ ) and maximum strain ( $\epsilon_m$ ) of the compositions was determined by mechanical testing machine. Several grains have been formulated in length 125 mm and diameter 25 mm. Selective compositions were placed in oven at -20 °C and +50 °C for 2 h [19]. The results are recorded in table 2.

### 2.5. Ballistic performance measurements

Pressure transducer named TELDYNE TABER was used to determine the performance of the compositions. The system of measurements contains data acquisition system to analyse the electrical

signal, calibrator, amplifier, calibrator, and ultra violet recorder. Two-inch rocket motor was used to determine the operating pressure and the average burning rate of the samples. An 8mm throat diameter was used in this study at temperature  $-20$  and  $+50$  °C respectively. The measurements are reported in table 3.

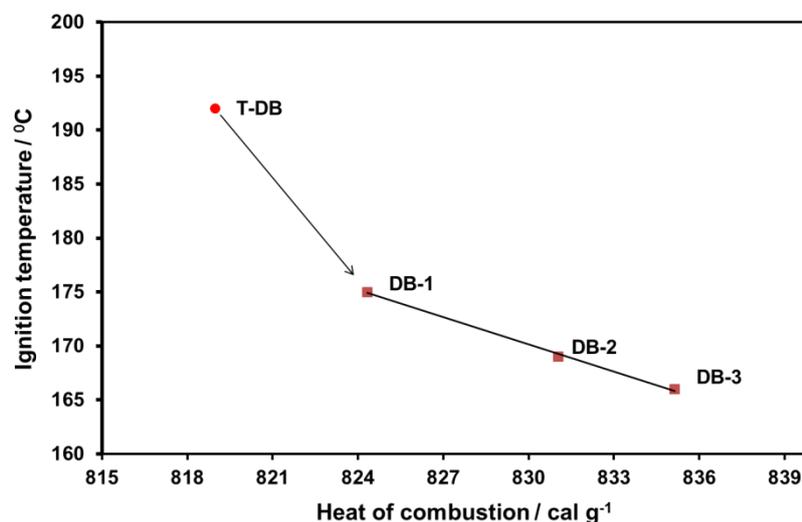
### 3. Results and discussions

Table 2 presents the ignition temperature of the samples. T-DB has temperature of ignition higher than the rest of the samples. A decreasing of the ignition temperature was observed as the percentage of the copper oxide in the composition increases.

**Table 2.** Measured data for the studied samples

Data	T-DB	DB-1	DB-2	DB-3
Ignition temperature [°C]	192	175	169	166
Heat of combustion [cal/g]	818.98	824.32	831.05	835.13
Max. stress, $\sigma_m$ [MPa]	1990.37	2571.52	2724.18	2798.37
Max. strain, $\epsilon_m$ [%]	31.41	37.78	40.28	41.12

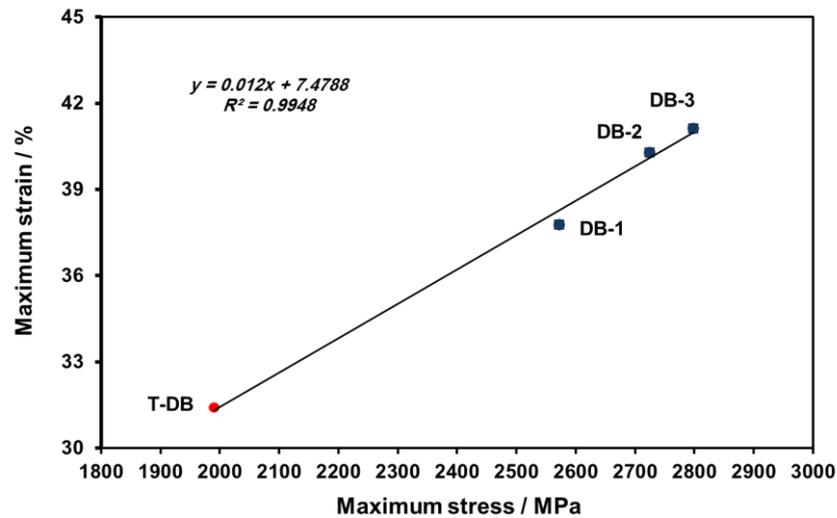
Regarding to the heat of combustion, T-DB has the lowest combustion heat of the studied samples. Addition of copper oxide increased the combustion heat. Figure 1 presents a comparison between the ignition temperature of the samples and their heat of combustion. Obvious decrease of the ignition temperature was observed due to increasing the percentage of copper oxide in the compositions. While the heat of combustion is increased by increasing of the percentage of copper oxide. It means that T-DB is more thermally stable compared with the studied samples.



**Figure 1.** Comparison between the ignition temperature of the samples and the heat of combustion.

The mechanical parameters represented by the maximum stress and strain elongation of the samples are reported in table 2. It was observed that addition of copper oxide as a part replacement of lead stearate improved the mechanical properties of these propellants at the normal temperature that

affect the functionality of the rockets [20]. A comparison between the maximum stress and strain of the compositions is plotted in figure 2. It is obvious that T-DB has low values compared with the other compositions. The enhancement of the mechanical properties of compositions based on copper oxide could be due to the morphology of the crystals and the homogeneous mixing of the ingredients.



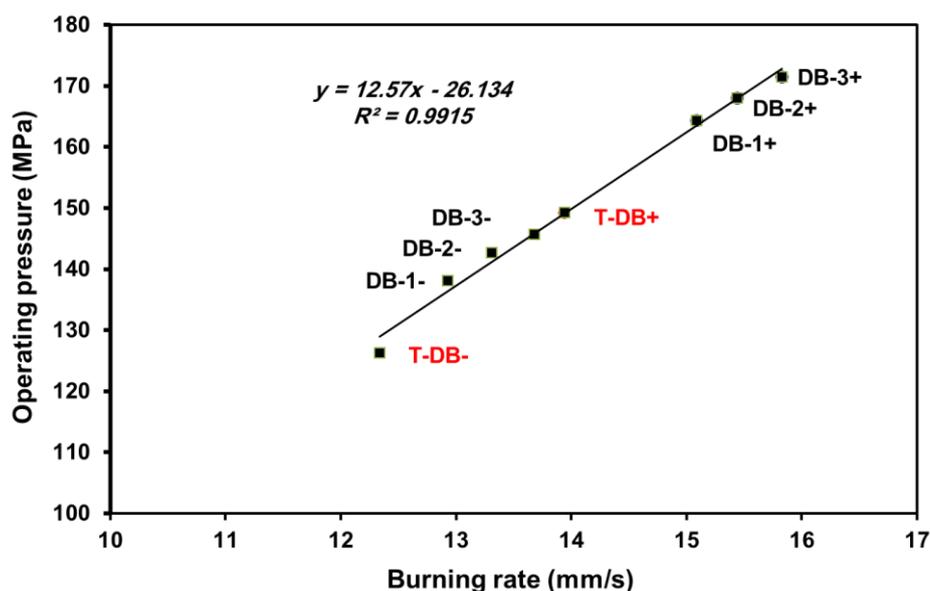
**Figure 2.** Comparison between the maximum stress and maximum strain of the compositions

The ballistic performance of the compositions measured using the two-inch motors are reported in table 3.

**Table 3.** Performance properties of the prepared compositions

Sample No.	Experimental measurements			
	at 50 °C		at -20 °C	
	P <sub>c</sub> [bar]	r <sub>b</sub> [mm/s]	P <sub>c</sub> [bar]	r <sub>b</sub> [mm/s]
T-DB	149.23	13.94	126.30	12.34
DB-1	164.33	15.09	138.12	12.93
DB-2	168.01	15.44	142.68	13.31
DB-3	171.47	15.83	145.72	13.68

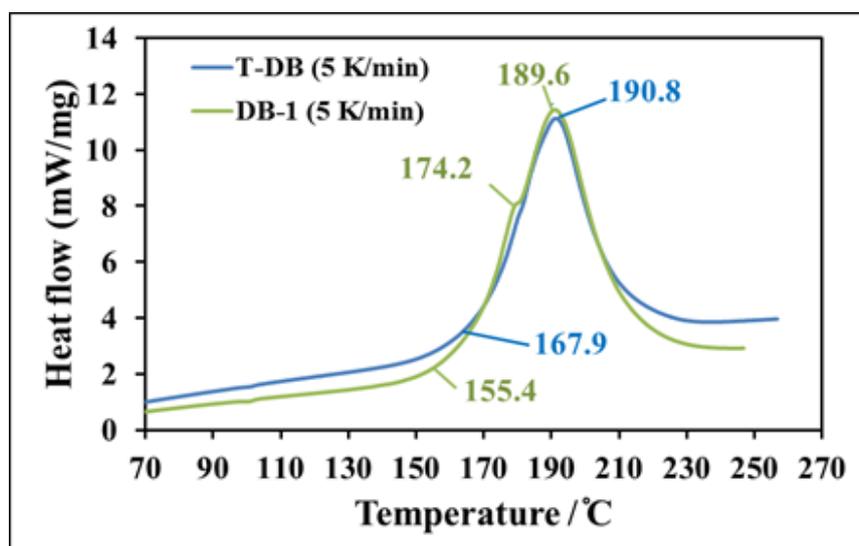
In this study, interesting relationship was observed between the burning rate and the operating pressure of the samples. The burning rate increases as the percentage of copper oxide increases in the samples. In addition, the burning rates at 50 °C are higher than that at -20 °C for each specific sample and the pressure of the compositions was increased by increasing the temperature.



**Figure 3.** Comparison between the burning rate and the operating pressure

By comparing all the results obtained, DB-1 was selected to study its thermal behavior, compared with the T-DB. DSC curves of the selected samples are presented in figure 4.

It was observed that the decomposition of DB-1 started at 155 °C (onset decomposition temperature) while the T-DB decomposition started at 167.9 °C. Lowering of the onset decomposition temperature is due to the effect of copper oxide. In addition, a notch appeared at 174.2 for the DB-1 sample followed by the maximum peak decomposition at 189.6 °C. This result is compatible with the result of the ignition temperature. The ignition temperature of DB-1 is at 175 °C which is very close to the peak observed at 174.2 °C. Also, the maximum decomposition temperature of T-DB at 190.8 °C is very close to its ignition temperature (192 °C). The thermal behavior of the samples confirms that addition of copper oxide to T-DB decreased the decomposition temperature and affects the thermal stability of the propellant.



**Figure 4.** DSC thermogram of the samples

#### 4. Conclusion

The addition of copper oxide as burning rate modifier lowered the ignition temperature of the traditional double base propellant while the heat of combustion was increased. Also, the heat of combustion increase as the percentage of copper oxide increase in the composition. On the other side, the mechanical properties were improved by increasing the percentage of copper oxide in the composition. Samples contained copper oxides have high performance compared with the traditional double based composition. The burning rate increases as the percentage of copper oxide increases. Regarding to the thermal behavior, the traditional double base has higher thermal stability than samples containing copper oxide.

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