Cobalt-based modifiers in aluminized solid propellants

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1. Background

- In solid rocket motors, the propellant grain contains both fuel and oxidizer in a single solid phase and serves as the energy source for the system. Such propellants are widely used in missiles thanks to their high energy content, good reliability, inherent safety, and long storage life, which make them attractive for many chemical-propulsion applications. Metallic particles (such as Al) combined with the solid propellant improve its performance providing an increase in specific impulse I_{sp} , characteristic velocity C^* and more.
- The burn rate of a solid propellant, given by the relation $\dot{r} = a * P_c^n$, is a criterion of utmost importance since it is the factor that affects the motor thrust and directly the speed of the aircraft. This parameter can be influenced by combining catalysts.

2. Objective

The objective of the research is to measure the burn rate of solid propellants with the addition of catalysts in new energetic compositions. Additionally, the study aims to find a correlation between the measured burn rate and the operating pressure in the rocket motor.

3. Methods and Materials

- Preparation and casting of propellants with 3 types of combustion catalysts with a mass fraction of 0.5% and 2%.

Table 1- Catalyst composition

Catalyst Type	Baseline	Silica	C1	C2
Catalyst Composition	-	SiO_2	$SiO_2/Co(OH)_2$	$SiO_2/Co(OH)_2$ H_2O_2 treated

<u>Catalyst Preparation:</u>

• Silica: Used as a high–surface-area (~200 m²/g), stable carrier that improves dispersion of active species and can enhance catalytic effects.
• C1: Cobalt hydroxide nanoparticles were seeded on silica to investigate their catalytic properties for SOX/NOX oxidation.
• C2: $SiO_2/Co(OH)_2$ was treated with hydrogen peroxide to alter cobalt's oxidation state, enhancing its catalytic performance.

Table 2- C1 propellant composition (mass fraction)

Binder			Oxidizer	Energetic Additive	Catalyst	Total
HTPB	DOA	IPDI	AP 200 μm	Al	C1	
12.55%	3.80%	2.84%	64.05%	14.78%	1.97%	100.00%

- Density tests have been conducted on samples that differ in the catalyst aspect, and compared to the theoretical value of 1.73 g/cm^3.

Table 3- propellants density results

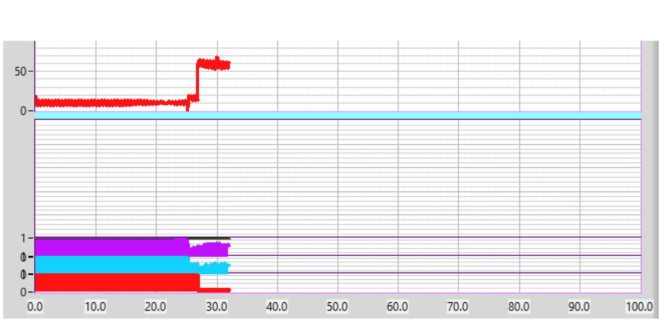
Catalyst type	silica-0.5%	C1-0.5%	C2-0.5%	C1-2%	C2-2%
Density [gr/cm^3]	1.55	1.44	1.58	1.38	1.43

<u>experimental procedure:</u>

- Inserting the propellant into the pressure chamber where it is being held on a stand and cutoff and ignition wires pass through it.
- Taking the results of the experiment and measuring the burn rate using the equation:

$$\dot{r} = \frac{\Delta l}{\Delta t} = \frac{distance\ between\ two\ cutoff\ wires}{time\ in\ seconds} [\frac{mm}{sec}]$$

- Typical output from the wire cutoff time monitoring system.

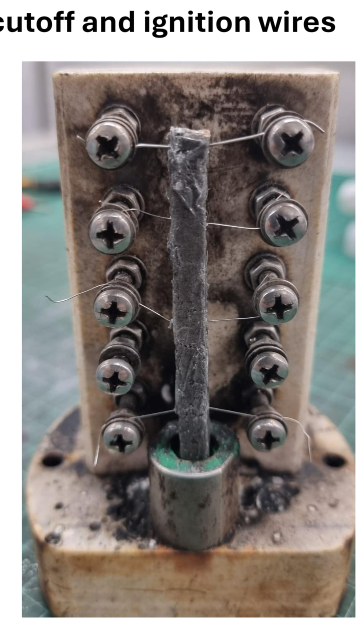


A visual indication of the cutoff wire disconnection in the software

Pressure	Temperatu	Wire	Wire	Wire	Wire	Time
76.22560402	0	20	0	20	0	24.7
85.3394378	0	0	0	20	0	25.2
89.80141892	0	0	0	0	0	26.3

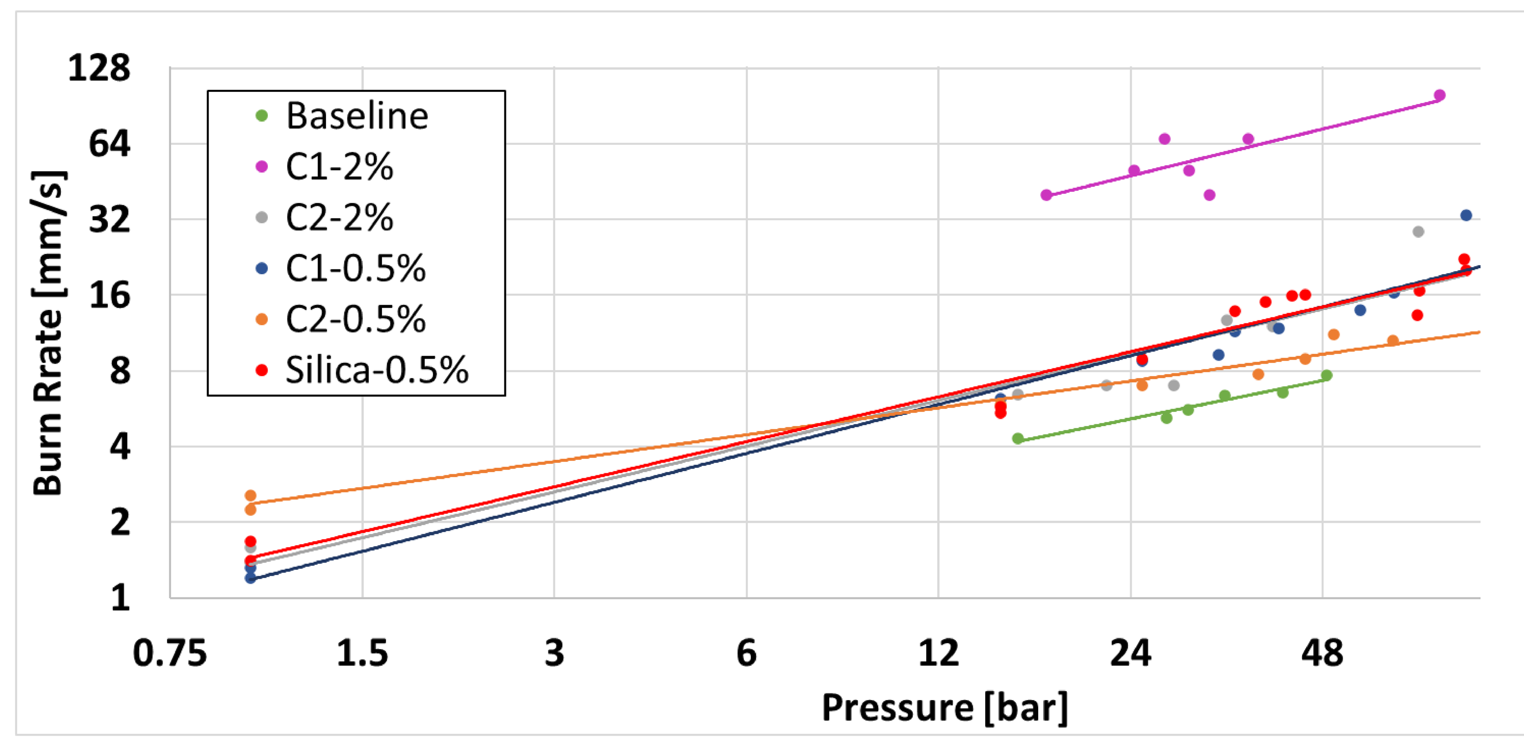
An indication of the cutoff wire disconnection

Fixed solid propellant with cutoff and ignition wires



4. Results

- The results of the study are presented in a graph that concludes the experiments with different catalysts: Baseline; Silica (SiO_2, 0.5%); C1 ($SiO_2/Co(OH)_2$, 0.5%, 2%) ; C2 ($SiO_2/Co(OH)_2$, 0.5%, 2%).



Burn rates vs operating pressure

Table 4 - burn rate and pressure equations. Burn rate is given in [mm/s] and the pressure is given in [bar]

Mixture	Pressure range [bar]	Burn rate equation
Baseline	16-49	$\dot{r} = 1.02 * P_c^{0.51}$
Silica-0.5%	1-80	$\dot{r} = 1.44 * P_c^{0.59}$
C1-0.5%	1-80	$\dot{r} = 1.18 * P_c^{0.65}$
C1-2%	17-73	$\dot{r} = 6.7 * P_c^{0.62}$
C2-0.5%	1-84	$\dot{r} = 2.36 * P_c^{0.35}$
C2-2%	1-67	$\dot{r} = 1.35 * P_c^{0.61}$

5. Summary & Conclusions

Table 5 - Propellant Performance Summary

		Propellant	Baseline				
		Pressure [bar]	15	25	35	40	45
Propellant	pressure [bar]						
silica-0.5%	15		134%				
	25			171%			
	35				218%		
	40					243%	
	45						209%
C1-0.5%	15		143%				
	25			168%			
	35				179%		
	40					181%	
	45						181%
C2-0.5%	15		136%				
	25			134%			
	35				122%		
	40					136%	
	45						115%
C1-2%	15		928%				
	25			960%			
	35				1045%		
	40					613%	
	45						518%
C2-2%	15		150%				
	25			134%			
	35				199%		
	40					185%	
	45						156%

- **C1-2%** achieves the highest improvements, reaching **1045%** at 35 [bar], indicating superior catalytic performance. Previous works had also indicated this catalyst to be the most effective.
- Other compositions also increase the burn rate significantly (up to 209% compared to the baseline).
- The figure above provides experimental support for the empirical burn-rate law, showing that all examined catalysts and concentration exhibit a clear increase in burn rate as the combustion pressure rises. This trend is consistent for each propellant composition and demonstrates that the measured data follow the expected pressure dependence.
- C2-0.5% exhibits relatively low pressure exponent (0.35 compared to 0.51 of the baseline), while most compositions present increased "n" (0.59-0.65).

6. Future Work

- **Agglomeration Tests**: Examine cobalt hydroxide catalysts' effect on particle clustering and combustion efficiency.
- **Mass Fraction Study**: Test propellants that contains 2% Silica as a catalyst to optimize burn rate and pressure sensitivity.