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Investigation of Thermal Analysis and Performance of Firecracker Composition by Reduction of Aluminum Metal Powder

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Abstract:
In the firecracker industry, during involved in the various manufacturing process of a firecracker, employees are affected by different health and safety hazards in their workplace, and also people who are celebrating by the bursting of crackers also getting affected by exposure to different contaminated particles. In general, the firecracker is made by using different chemical powders like potassium nitrate, aluminium, and sulfur with a ratio of 60%, 20%, and 20%. With consideration of the aforementioned issues, the new firecracker is manufactured by reducing nano aluminum powder at different compositions like 2%, 4%, 6%, 8%, and 10%, it is balanced by Tamarind Seed Powder (TSP). Thermal analysis like thermogravimetric analysis is carried out. The generation of residue was gradually decreased when the reduction of aluminium metal powder and it supports reducing the pollution rate. To understand the reactivity of the chemical mixture, sensitivity tests were carried out. There is no frictional reactivity for all modified chemical compositions. All the samples have come under a very sensitive category other than the Al10 sample. So it helps to reduce the safety hazards during handling. The performance characteristic like noise level of the firecracker made by using these modified chemical mixtures has come under optimum level.

INTRODUCTION

In fireworks industries, there are more accidents are happened involving the manufacturing processing of firecracker like handling with different chemical powders, during storage and transportation of firecrackers [1]. The reason for occurring accidents is to use more quantities of chemical mixture beyond the permissible level, unsafe act, and unsafe condition. The unsafe act is employee's carelessness, mishandling of chemical powders, violating the safety rules and regulations given by standard as well as the company. The unsafe condition is the usage of defective tools and equipment, the temperature of the working environment, drying condition, and humidity. Generally, Pyrotechnic mixtures are the energetic compounds leads to thermal decomposition on friction, impact, and ignition are obtained by mixing of finely alienated chemical powders that are proficient of undergoes self-sustaining combustion reaction [2]. The chemical powders are used in firework industries are naturally hazardous materials due to the properties of high sensitiveness to temperature, friction, impact, and pressure. Firecracker consists of oxidizer, fuel, colour enhancing chemical powders, and binder [3]. The bursting of a firecracker, releases contaminated gases and pollute the environment. The rate of pollution is controlled by changing the particle size of the chemical mixture and also modifying the chemical mixing proportion. The fine particle size of the

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chemical mixture has more sensitive than coarse powder [4]. The particle size of the chemical mixture is used in this work is nano level. The nano-sized aluminium powder in the firecracker chemical composition and reported that the nano-sized chemicals show high thermal energy content and high sensitivity for various compositions of flash powder [5]. When using nanopowder the performance has been increased and the formation of contaminating is also reduced during bursting. The performance of the firecracker mainly depends upon the friction, impact sensitivity, and noise level, and emission rate during the bursting of the cracker. The fine aluminium metal powder liberates more amount of heat during its processing and makes a more hazardous environment in working place [6]. During handling with aluminium metal powder its gives many health issues to a human being. Hence an attempt is made specifically with nano chemical powders of aluminium to reduce the generation of residue without compromising the performance of the cracker. The details of raw materials used in this work are mentioned [7] and Table 1 represents the chemical composition that is used to make a firecracker.

Table 1: Chemical composition used in fabricating firecrackers

Sample name	**Chemical composition (%)**			
	Potassium nitrate (KNO_3)	**Aluminium (Al)**	**Sulfur (S)**	**Tamarind seed powder (TSP)**
FPSN	60	20	20	-
Al 18	60	18	20	2
Al 16	60	16	20	4
Al 14	60	14	20	6
Al 12	60	12	20	8
Al 10	60	10	20	10

Experimental setup

Thermal Analysis

The firecracker chemical compositions were taken and the thermal properties of the chemical composition were examined to investigate the mass loss concerning heat by using in Thermogravimetry (TG) analysis instrument made by Perkin Elmer and the Model of the instrument is DSC 4000 System. This thermal analysis is conducted in a nitrogen atmosphere (Inert atmosphere). The temperature range is between 35 °C to 995 °C and the heating rate is 20 °C min^{-1}. The quantity of chemical composition is used for this analysis is approximately 5.0 mg was used for each thermal analysis.

The sensitivity tests like friction and impact sensitivity tests and the performance test like noise level tests were carried out as per the standard procedures and it is described [7].

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RESULT AND DISCUSSION

Thermogravimetry analysis test

Thermogravimetry (TG) analysis is a very important analysis that helps to identify the thermal degradation of energetic materials like firecracker chemical composition. The Thermogravimetry curve of FPSN is given in Fig.1. The TG analysis of Al2, Al4, Al6, Al8, and Al10 was shown in fig.2. In fig.1, at the beginning of the TG curve of FPSN, there was an escalation in the mass of the FPSN and then gradually reduced with an increase in temperature. This may happen due to the basis of Archimedes effect during the starting of the thermal analysis. Before increasing the temperature of the chemical composition, the inert gas such as N_2 gas flows to the working atmosphere which causes to upwards the sample pan and it leads to an increase in the mass of the samples is about approximately 0.9 g during the initial stage of the experiment. As rises in the temperature, the density of samples slightly decreased and it is stabilized when the sample pan moves downward direction. This kind of observation has not happened for other samples and this has confirmed that this has happened at the initial stage of the thermal analysis. For a normal firecracker, the first step the mass loss of about 21.19%. It is caused by the discharge of SO_x or N_2 gases to the atmosphere [8] and it is created during the thermal degradation process.[9] and second, step the mass loss is 18.06%. It was experienced that there was a constant mass and subsequently an increase in mass was noticed. This mass stability was because of the phase transition of amorphous Al_2O_3 to γ-Al_2O_3 followed by the increase in mass in the Thermogravimetry curve. This denotes that thermal decomposition and chemical reactions have occurred and cause which mass change occurs.

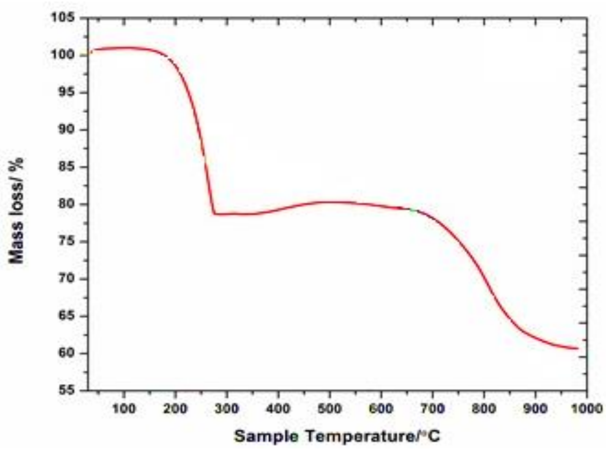

Fig.1(a) TGA for Normal firecracker sample

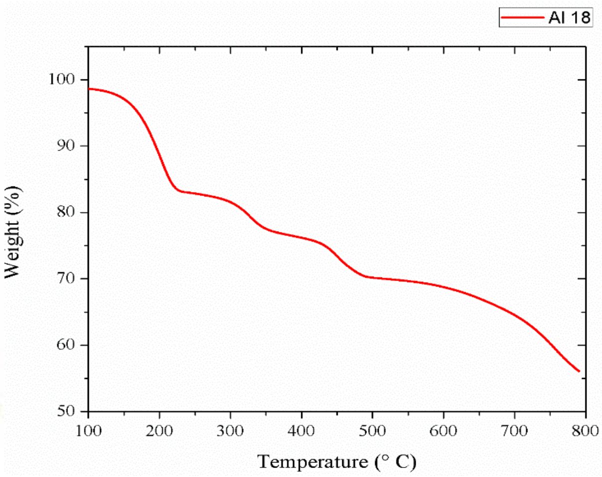

Fig.1(b) TGA for Al18 sample

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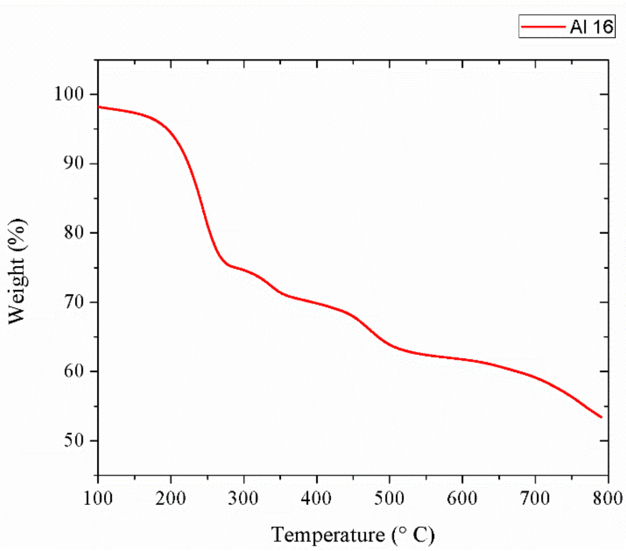

Fig.1(c) TGA for Al16 sample

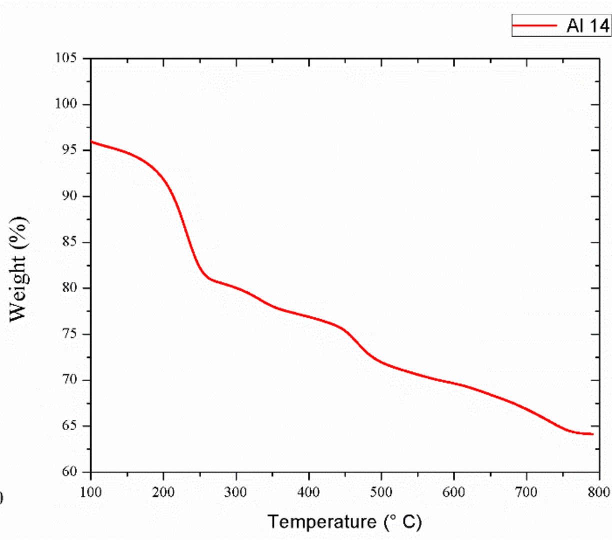

Fig.1(d) TGA for Al14 sample

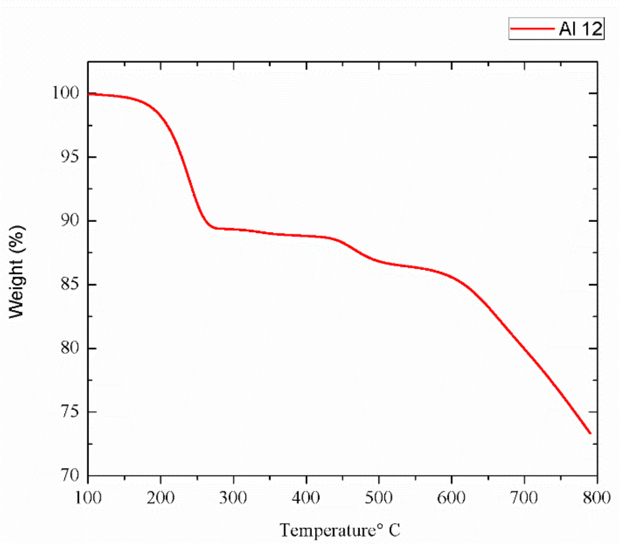

Fig.1(e) TGA for Al12 sample

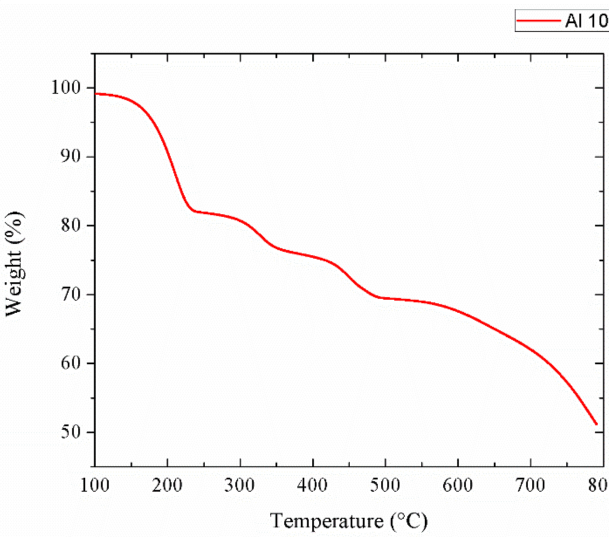

Fig.1(f) TGA for Al10 sample

Fig.1 TGA analysis for firecracker samples

Similarly the remaining samples thermogravimetric analysis carried out. For all the samples the temperature between 250°C and 480°C regions, there were two temperature slopes observed and it is due to the Devolatilization[10] of Tamarind Seed Powder. Devolatilization in the TG curve is obtained during the thermochemical conversion process involving biomass.[11]. This work mainly focused on the presence of residues in all the samples and their influence on environmental pollution. Because when the generation of residues is less it will pollute the environment lesser. When it is high, the possibility of environmental pollution also higher. For normal firecracker chemical composition, the presence of residue after mass loss is 39.25%. Similarly Al18 the residue after the mass loss is 43.88%. The residue formation for the Al16 sample is 46.48%. For the Al14 sample, it is 35.74%. The residue percentage for the Al12 sample is 26.53% and for the Al10 sample, it is 48.69%. This behaviour due to Thermal Decomposition of the chemical mixture, Vaporization of sulfur powder between the temperature range is 225 to 444°C, Devolatilization of celluloses of Tamarind Seed Powder between the temperature range is 325 to 480°C, amorphous transition Al_2O_3 to γ-Al_2O_3 between the temperature range is 500 to 620 °C, aluminium melting point temperature 660°C and due to thermal decomposition of K_2O. Based on the residue formation Al 14 and Al12 samples pollute the environment lesser. Because when we are using these samples for preparing the firecracker, attain the complete combustion and produce less contaminated gases due to the formation of less residue. For other samples the residue generation level is high due to this it may possible to pollute the environment higher. The sample mass losses concerning temperature are summarized in Table.2 and 3.

Table.2 TG analysis of FPSN

Sample	**Sample mass loss/%**			**Temperature/°C**			**Thermal events**
	From	**To**	***Mass loss difference***	**From**	**To**	***Temp Difference***	
FPSN	100.00	78.81	21.19	139.54	275.36	135.82	Violent thermal decomposition of a chemical mixture
	78.76	60.70	18.06	277.03	972.94	695.91	Vaporization of sulfur (225-444 °C) [12]
							Amorphous transition Al_2O_3 to γ-Al_2O_3 (~ 500 to 620 °C)
							Aluminium melting point reached (660°C)
							K_2O Thermal decomposition occurs (700-950 °C)[12]
	Delta Y		39.25				

Table.3 TG analysis of modified chemical compositions

Modified sample	**Mass loss (%)**			**Mass loss**			**Thermal events**
	From	**To**	**ΔY**	**From (°C)**	**To (°C)**	**ΔT(°C)**	
Al18	99.97	83.47	16.5	27.819	227.336	199.517	Thermal Decomposition
	83.47	77.659	5.811	227.336	361.97	134.634	Vaporization of sulfur (225-444 °C) [12]
							Devolatilization of hemicelluloses of Tamarind Seed Powder (approximately 250 to 325 °C)[13,14]

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	77.659	70.73	6.929	361.97	481.31	119.34	Vaporization of sulfur (225-444 °C) [12] Devolatilization of celluloses of Tamarind Seed Powder (approximately 325 to 480 °C)[13,14]
	70.73	56.09	14.64	481.31	790.46	309.15	The transition of amorphous Al_2O_3 to γ-Al_2O_3 (~ 500 to 620 °C) The melting point of Aluminium (660°C) [15] K_2O Thermal decomposition occurs (700-950 °C)[12]
	Delta Y		43.88				
Al16	99.90	75.53	24.37	29.26	275.73	246.47	Thermal Decomposition
	75.53	71.107	4.42	275.73	353.65	77.92	Devolatilization of hemicelluloses of Tamarind Seed Powder (approximately 250 to 325 °C)[13,14]
	71.107	63.30	7.81	353.65	515.39	161.74	Vaporization of sulfur (225-444 °C) [12] Devolatilization of celluloses of Tamarind Seed Powder (approximately 325 to 480 °C)[13,14]
	63.30	53.42	9.89	515.39	789.89	274.5	1.The transition of amorphous Al_2O_3 to γ-Al_2O_3 (~ 500 to 620 °C) 2. The melting point of Aluminium (660°C) [10] K_2O Thermal decomposition occurs (700-950 °C)[12]
	Delta Y		46.48				
Al14	99.95	95.62	4.33	26.03	113.05	87.02	Thermal Decomposition
	95.62	90.87	4.75	113.05	207.82	94.77	
	90.87	80.47	10.4	207.82	283.64	75.82	Vaporization of sulfur (225-444 °C) [12]
	80.47	77.26	3.21	283.64	382.20	98.56	Devolatilization of

							celluloses of Tamarind Seed Powder (approximately 325 to 480 °C)[13,14]
	77.26	71.44	5.82	382.20	516.40	134.2	The transition of amorphous Al_2O_3 to γ-Al_2O_3 (~ 500 to 620 °C)
	71.44	64.15	7.29	516.40	790.25	273.85	The melting point of Aluminium (660°C) [15] K_2O Thermal decomposition occurs (700-950 °C)[12]
	Delta Y		35.74				
Al 12	99.87	96.92	2.95	26.56	214.65	188.09	Thermal Decomposition
	96.92	89.37	7.55	214.65	290.46	75.81	Vaporization of sulfur (225-444 °C) [12]
	89.37	87.03	2.34	290.46	489.86	199.4	Devolatilization of celluloses of Tamarind Seed Powder (approximately 325 to 480 °C)[13,14]
	87.03	83.41	3.62	489.86	647.56	157.7	Vaporization of sulfur (225-444 °C) [12]
	83.41	73.34	10.07	647.56	782.56	135	K_2O Thermal decomposition occurs (700-950 °C)[12]
	Delta Y		26.53				
Al10	99.88	94.76	5.12	36.80	182.05	145.25	Thermal Decomposition
	94.76	81.74	13.02	182.05	260.14	78.09	Vaporization of sulfur (225-444 °C) [12]
	81.74	75.95	5.79	260.14	379.93	119.79	Devolatilization of celluloses of Tamarind Seed Powder (approximately 325 to 480 °C)[13,14]
	75.95	68.95	7	379.93	551.27	171.34	Vaporization of sulfur (225-444 °C) [12]
	68.95	64.27	4.68	551.27	663.48	112.21	The transition of amorphous Al_2O_3 to γ-Al_2O_3 (~ 500 to 620 °C) The melting point of Aluminium (660°C) [15]
	64.27	51.19	13.08	663.48	786.56	123.08	K_2O Thermal

							decomposition occurs (700-950 °C)[12]
	Delta Y		48.69				

Sensitivity test result

It is observed from the impact sensitivity result analysis the limiting impact energy for Al 10 sample is 7.848J. When the dead weight of 2 Kgs is released from the height level of 0.40m to the Al 10 sample, the flash does not occur. It shows that there is no reactivity property is in this sample when aluminium metal powder is reduced by 10%. Even though the sulfur content is balanced in this sample it not supporting to enhance the chemical reaction. So Al 10 sample does not meet the explosion category. Other samples like Al14 and Al 12 samples come under the very sensitive category. The limiting impact energy of these samples is 4.905Joules. The remaining samples like Al18 also come under the very sensitive category and the limiting impact energy value is 3.924Joules. For the Al16 sample, the limiting impact energy is 3.532 Joules. It shows that the reactivity of the Al16 and Al18 samples is slightly higher than Al14 and Al12 samples. Compared to Al 10 samples all other samples are feasible for use as firecracker chemical composition.

It is observed from friction sensitivity test analysis, all the samples other than normal firecracker do not have sensitivity property. It was observed that during handling of modified chemical compositions there is no safety hazardous have been presented in the working environment. So the safety aspect in the workplace is improved during using of Al18, Al16, Al14, and Al12 samples. But the performance of the Al10 sample is not suitable for firecracker applications.

Noise level test

It is observed from the Noise level test, the noise level of the firecracker which is made by normal firecracker chemical composition (0.3g) is 107.9dB(A) and 131.6dB(C) and during the bursting of 2g of chemical mixture, it is 124.2dB(A) and 147.9dB(C). It is slightly higher than the permissible level given by Noise Pollution Control Board and Environmental Protection Act. The noise level for modified firecracker chemical compositions is at the optimum level and within the permissible level. The noise level of the firecracker which is made by the Al10 sample is slightly less than other modified samples. So that it is not suitable for firecracker manufacturing applications.

CONCLUSION

- The Al-10 sample chemical composition does not meet the explosion category and the remaining samples come under the very sensitive category. All the samples like Al18, Al16, Al14, Al12, and Al10 do not have frictional sensitivity property. So, the safety hazard has been decreased while reduction of aluminium metal powder along with normal firecracker chemical composition.

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- The noise level of the samples like Al18, Al16, Al14, Al12 and produces optimum noise level and it is within the permissible limit given by the Noise Pollution Control Board and Environmental Protection Act. The noise level of the Al10 sample is slightly higher than other samples.
- To understand the residue particle of firecracker chemical composition, thermogravimetric analysis was carried out. The generation of residue was gradually decreased when the reduction of aluminium metal powder and it helps to reduce the pollution rate. Al14 and Al12 samples are suitable for making firecracker and it helps safeguard the environment and human beings in the workplace.

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