Recycling of Global Consumer Fireworks

Andrew Tang, Andy Y. F. Tang and Paul Z. J. Peng
Tian Cheng Pyrotechnics Laboratory, Lihua Village, Yanxi Town, Liuyang City, Hunan, China 410304
Email: atang@tcpyrolab.org

Abstract: *Consumer fireworks is one of the two major fireworks sectors, professional display fireworks and consumer fireworks, in the fireworks industry. It is estimated that consumer fireworks occupy about half of the market share in the global fireworks industry. In terms of packaging materials being used in the consumer fireworks sector, it is definitely true that far more material is being used than in the professional display fireworks sector. This study is a market survey of global consumer fireworks that are on sale in different countries. It was carried out to see what material is being employed in global consumer fireworks and how it is used. The environmental pollution from shooting consumer fireworks is considered from different points of view. Recycling of consumer fireworks has been introduced in China. Innovation in new materials for consumer fireworks is beginning in China.*

Keywords: *Consumer fireworks, recycling, packaging materials, environmental pollution, breakdown of material, NEC, paper*

Introduction

Recycling of fireworks is rarely heard of by consumers or even people working in the fireworks industry. It is commonly accepted that all fireworks are used once and disposed of immediately afterwards, and that it does not matter how and where it is disposed of. In China this is very similar to all types of packaging for consumer goods such as foodstuffs, unless you want to use the packaging again.

The Green Power organization in Hong Kong has conducted an annual survey on people's consumption and celebration habits.[1] The analysis shows the habits of moon cake wastage, and that recycling moon cake packages is still a waste problem. Million of moon cake packages are dumped after the Mid-Autumn Festival. From study data in 2011 September, there were about 47 packaging components used in some types of retail moon cake while the average is 11

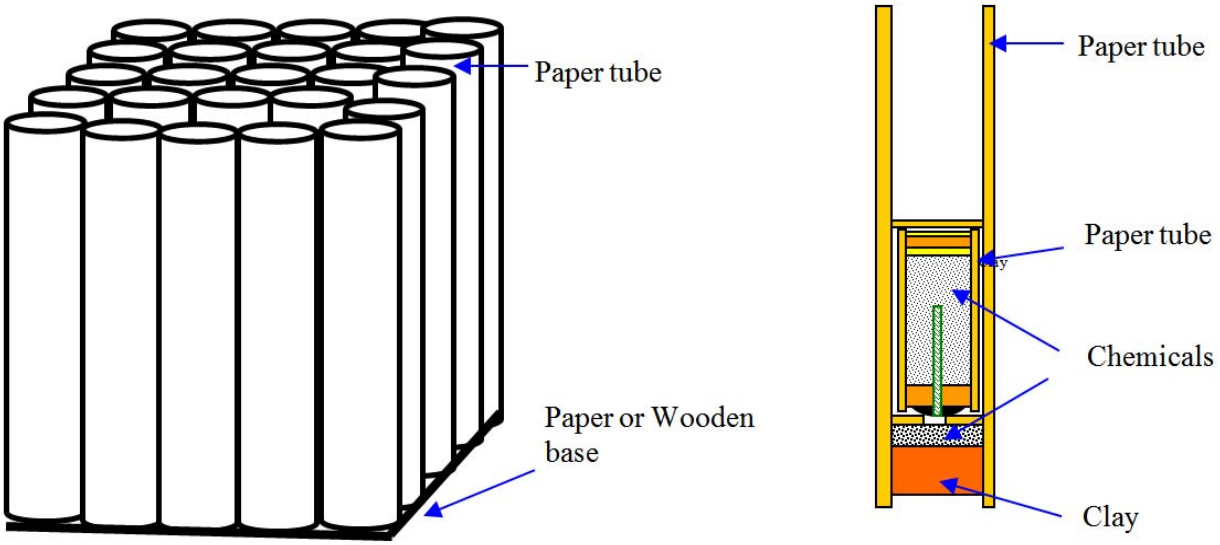

Figure 1. *Structure of consumer fireworks (e.g. cake) showing general inner construction.*

Article Details ***Article No:- 0095***
Manuscript Received:- 29/08/2012 ***Final Revisions:- 13/11/2012***
Publication Date:- 25/11/2012 ***Archive Reference:- 1518***

Table 1. *Distribution of consumer fireworks samples in the study*

Type	No of samples	Range	
		Total mass (g)	NEC (g)
Aerial shells	5	533–606	116–133
Cakes	15	110–10637	16–1124
Firecrackers	9	1.6–857	0.4–107
Fountains	20	16.5–1944	0.4–296
Ground spinner	4	10.6–46.5	2.1–8.4
Helicopters	9	10.3–281.5	3.3–67.4
Magic whip	1	248	134
Missile	3	95–388	18.5–70.4
Novelties	7	2.6–217	1.1–200
Party poppers	5	2.6–354	0.01–0.7
Rockets	5	80.3–359	16.6–150
Roman candles	5	70–740	6.6–107
Sparklers	4	1.3–17.7	0.8–6.9
Others	7	[a]	[a]
TOTAL	99	–	–

[a] Some samples were specially designed and so could not be grouped into different groups. The range of gross weight and NEC were not meaningful.

packaging components.

Normally packaging of consumer fireworks is simple and straightforward. The first ancient Chinese firecrackers contained no packaging, but were simply black powder filled in a piece of bamboo[2] closed at one end. Packaging for the old style fireworks was concerned only with safety and attractiveness. When one looked at a firing site after the consumer had used fireworks, there were torn papers and broken components spread around on the ground. Most of the environmental pollution complaints arising from shooting fireworks concerned air and noise pollution, and much less focused on the left over waste paper and components. This study does not describe the impact caused by pyro-chemicals but focuses on the packing components of consumer fireworks or other material that is left over on the ground after using fireworks. A preliminary similar report was presented .[3]

Consumption of consumer fireworks

All consumer fireworks function using different formulations, combinations and percentages of black powder, stars and effect charges. All of these formulas are composed of chemicals. The functioning of fireworks creates the effects that are its primary performance. As is well known the effects are light, gases and sounds that are produced in the air.[4] During functioning, these chemicals react and generate oxides[5] in the form of small particles, gases, moisture and some burnt debris. These small particles or gases are blown away by the surrounding air. After the functioning of fireworks, all that is left in the air are smoke and gases. There is increasing attention to the environmental impact of these smokes and gases. A lot of studies have been carried out to understand the impact and much research and development is still continuing to eliminate it. Figure 1 shows a typical construction of one type of consumer firework called a battery of shot tubes or the generic term, cakes.

After functioning of fireworks, all that is left over on the ground is packing materials that used to hold chemicals. Since people are allowed to handle and buy consumer fireworks, the main criteria for fireworks packaging are the safety and attractiveness of the fireworks. In the early days of fireworks manufacturing, all packing materials were made mainly of paper and clay. The first firecracker was made of black powder and bamboo. Nowadays plastics and metals have been introduced. Some common items of consumer fireworks are shown in Figures 9 to 12.

Waste from consumer fireworks

Consumer fireworks are always packed or packaged

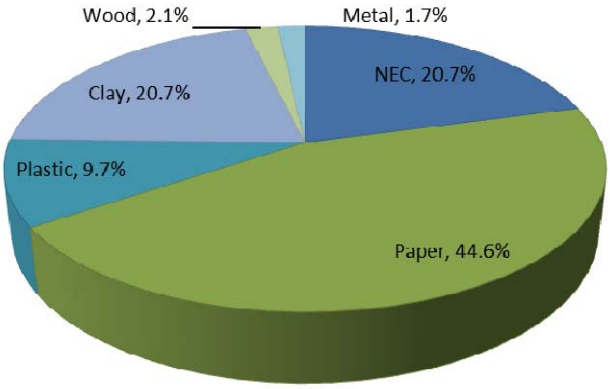

Figure 2. *Percentage of different materials used in consumer fireworks.*

in an attractive manner to draw consumers' attention. Of course manufacturers will ensure the package contains the maximum possible protection to consumers so as to provide safe transportation, handling and functioning.

The sole functioning of fireworks generated by pyrochemicals or net explosive content (NEC) is always the main concern of both consumer and audience. The NEC is composed of chemicals, mainly oxidizers, fuels, and reducing agents. These chemicals are simple and non-toxic or less toxic chemicals such as nitrates, perchlorates, metal powders, sulphur, and some metallic oxides. They are confined inside the paper tube, shell or both to create effects based on different requirements. After ignition of the leading fuse and the subsequent functioning of the firework, all chemicals react to form different forms of oxides. The by-products are water, and energy in forms of light and sound, and smoke. The residue of fireworks that is left on the ground is the waste or containers that used to hold those chemicals.

It is commonly found in China that most used fireworks that are left after firing are collected by waste packers because the material is worth money, similar to other recyclable materials such as glass, metal (aluminum) and plastics. Paper is the most collectible material in recycling of fireworks. It is collected almost immediately after firing in China. Then it is sold to recycling facilities and delivered to paper milling factories where paper is manufactured and supplied back to fireworks factories. See Figures 4 to 7 showing fireworks waste collected in China.

This study focused on the left over waste after the chemicals (NEC) have reacted to form gases and smoke.

Experimental

There were 99 samples randomly selected from different factories manufacturing consumer fireworks for different markets such as the US, EU, China etc. Among these there were different types of consumer fireworks, see Table 1. Their gross weights were measured and they were dismantled. Different materials such as chemicals (NEC), paper, clay, plastic, wood and metal were separated then their weights measured individually. The majority of these consumer fireworks were cakes and fountains because they were commonly available in factories which implies their large market share. Others were rockets, roman candles, small aerial shells, sparklers, helicopters, magic whips and missiles. Their distribution is shown in Table 1.

Results and discussion

Overall average of breakdown of materials in global consumer fireworks

The overall average percentage breakdown of the materials used in global consumer fireworks was 44.6% (w/w) of paper material, 20.7% (w/w) of clay

Table 2. *Breakdown of materials in consumer fireworks by regional market*

Region		NEC (%)	Pa (%)	Pl (%)	Cl (%)	Wo (%)	Me (%)
European		20.8	42.2	5.9	27.5	0.4	2.8
	Max.	63.8	73.5	66.9	70.0	9.6	36.2
	Min.	0.1	22.5	0.1	2.0	9.6	31.6
PRC		16.9	49.4	1.1	32.0	—	—
	Max.	32.0	70.3	7.4	54.0	—	—
	Min.	9.8	30.2	0.1	7.0	—	—
N. America		21.5	44.3	12.7	16.0	3.1	1.6
	Max.	92.0	82.9	64.3	64.7	36.4	57.9
	Min.	0.1	2.7	0.2	2.0	2.8	2.0

Note: No max./min. if there is no average result and absence was not counted as minimum.
NEC = Net Explosive Content; Pa = Paper; Pl = Plastic; Cl = Clay; Wo = Wood; Me = Metal.

Table 3. *Breakdown of materials in different types of consumer fireworks*

Type	NEC (%)	Pa (%)	Pl (%)	Cl (%)	Wo (%)	Me (%)
Aerial shells	21.6	59.4	4.0	14.7	0.0	0.0
Cakes	14.3	39.6	1.7	39.5	4.8	0.0
Firecrackers	14.4	33.1	1.4	50.1	0.0	0.0
Fountains	22.5	49.0	6.7	21.1	0.0	0.0
Ground spinner	27.9	52.4	1.2	17.7	0.0	0.0
Helicopters	23.3	56.0	4.5	14.8	0.0	0.2
Magic whip	54.1	21.8	24.2	0.0	0.0	0.0
Missile	20.1	21.7	56.0	2.1	0.0	0.0
Novelties	31.0	42.6	13.6	4.6	5.2	2.4
Party poppers	0.2	46.6	52.7	0.0	0.0	0.0
Rockets	28.3	44.9	7.1	8.5	10.7	0.0
Roman candles	13.6	72.4	0.0	12.0	1.8	0.0
Sparklers	42.6	19.0	1.3	0.0	0.0	36.9

material, 9.7% (w/w) of plastic material, 2.1% (w/w) of wood material and 1.7% (w/w) of metal material. Chemicals (NEC) occupied 20.7% by weight. See Figure 2.

Breakdown of materials in consumer fireworks by regional areas

If these samples were grouped by different regional areas such as European countries, USA and PRC, the distribution of material was as shown in Table 2. The percentage NEC was highest, 21.5%, for samples for the North American market, while that for the PRC market was the lowest, 16.9%. By contrast, the percentage of paper was highest for the PRC market, 49.4%, and lowest for the European market, 42.3%. In terms of clay material, the PRC market was

Table 4. *Breakdown of materials in different consumer fireworks (excluding NEC from the calculation)*

Type	NEC	Pa-LO (%)	Pl-LO (%)	Cl-LO (%)	Wo-LO (%)	Me-LO (%)
Aerial shells	0	75.8	5.1	18.8	0.0	0.0
Cakes	0	46.2	2.0	46.1	5.6	0.0
Firecrackers	0	38.7	1.6	58.5	0.0	0.0
Fountains	0	63.2	8.6	27.2	0.0	0.0
Ground spinner	0	72.7	1.7	24.5	0.0	0.0
Helicopters	0	73.0	5.9	19.3	0.0	0.3
Magic whip	0	47.5	52.7	0.0	0.0	0.0
Missile	0	27.2	70.1	2.6	0.0	0.0
Novelties	0	61.7	19.7	6.7	7.5	3.5
Party poppers	0	46.7	52.8	0.0	0.0	0.0
Rockets	0	62.6	9.9	11.9	14.9	0.0
Roman candles	0	83.8	0.0	13.9	2.1	0.0
Sparklers	0	33.1	2.3	0.0	0.0	64.3

Table 5. *Breakdown of materials used in cakes*

Materials	Average, grams	Max.	Min.
Gross weight	3376 (100%)	10 637	110
NEC	397.6 (14.3%)	1124	15.6
Paper	1459 (39.6%)	4949	38.4
Plastic	7.3 (1.7%)	48.1	5.1
Clay	1305 (39.5%)	4644	38.4
Wood	207.1 (4.8%)	1400	99.0
Metal	0	0	0

highest, 32.0% and the North American market was lowest, 16.0%. This shows that fireworks sold for the PRC market contain high percentages of paper and clay but least NEC. It was envisaged that the local transportation of fireworks was less expensive than overseas transportation. The packaging of consumer fireworks for the PRC market seems to be more bulky than that for other markets.

Breakdown of materials of different types of consumer fireworks

Different types of consumer fireworks function differently and so they are manufactured using different processes. The materials used, therefore, contain different amounts of different materials. For example sparklers contain a high percentage of metal because of the iron stick although the firecracker does not use metal at all. Hence the percentage breakdown of material is better presented in terms of its type. The breakdown of materials of each type of consumer fireworks is shown in Table 3.

After functioning of these fireworks, all pyro-chemicals reacted giving energetic effects such as sound, light, gases, moisture etc. The leftover materials were paper, plastic etc. Therefore percentages of leftover materials were different and were calculated without the percentage of NEC. The results are shown in Table 4.

Cakes

This type was the largest group of consumer fireworks available in all markets. Due to the similarity of their outer appearance, the sample size was smaller than that for fountains. The number of shot tubes within each sample differed so the performance effect was different too. Hence the higher the number of shot tubes and the higher its effect, the greater the NEC content of the sample. Besides NEC, paper and clay occupied about 80% by weight of this type. The breakdown of materials included mainly paper (39.6%), clay (39.5%) and NEC (14.3%). For a detailed breakdown refer to Figure 3. The maximum and minimum weights of materials are shown in Table 5.

Fountains

The second largest type of consumer fireworks was fountains, which extended from a single tube up to multiple tubes (battery of shot tubes). Due to the varied outer appearance, a larger number of samples was randomly chosen. Besides NEC, paper and clay were still the two main materials used to construct this type of consumer fireworks. More explicitly paper occupied about 50% by weight of its gross weight. The average waste from fountains consisted of paper 49.0%, clay 21.1% and plastic material 6.7% by weight. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 6.

Table 6. *Breakdown of materials used in fountains*

Materials	Average, grams	Max.	Min.
Gross weight	375.8 (100%)	1,944	40.0
NEC	70.9 (22.5%)	296.3	0.4
Paper	171.9 (49.0%)	788.7	12.4
Plastic	13.1 (6.7%)	110.7	0.7
Clay	115.9 (21.1%)	865.4	2.1
Wood	3.3 (0.3%)	65.2	0
Metal	0.0 (0.0%)	1.8	0

Table 7. *Breakdown of materials in helicopters*

Materials, grams	Average	Max.	Min.
Gross weight	116.7 (100%)	282	10.3
NEC	24.8 (23.3%)	67.4	3.3
Paper	64.3 (56.0%)	175.5	6.2
Plastic	4.8 (4.5%)	15.6	0.02
Clay	21.3 (14.8%)	79.2	0.7
Wood	0 (0%)	0	0
Metal	0.6 (0.2%)	6.1	0

Table 8. *Breakdown of materials in novelties*

Materials, grams	Average	Max.	Min.
Gross Weight	114.4 (100%)	217	2.6
NEC	37.5 (31.0%)	200	1.1
Paper	58.5 (42.6%)	160	0.5
Plastic	9.5 (13.6%)	37.9	0
Clay	5.7 (4.6%)	19.5	0
Wood	0.1 (5.2%)	0.9	0
Metal	2.3 (2.4%)	8.6	0

Table 9. *Breakdown of materials in firecrackers*

Materials, grams	Average	Max.	Min.
Gross weight	109.8 (100%)	857	1.6
NEC	13.2 (14.4%)	106.6	0.4
Paper	63.5 (33.1%)	530.4	0.4
Plastic	2.2 (1.4%)	18.7	0
Clay	29.8 (50.1%)	191	0.8
Wood	0 (0%)	0	0
Metal	0 (0%)	0	0

Helicopters

This type of consumer fireworks contained different designs. Metal and plastic materials were also introduced. There were 9 different samples randomly selected from factories. Besides NEC, the first two materials were paper, 56%, and 14.8% of clay. The lowest was plastic, 4.5% by weight. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 7.

Novelties

This type contained all 5 different materials because the type was more attractive to younger consumers on account of their appearance rather than their pyrotechnic effects. There were 7 different samples randomly selected from factories. Besides NEC, the first two main materials were paper, occupying 42.6% by weight and plastic, 13.6% by weight. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 8.

Firecrackers

This type of consumer fireworks was the traditional

Table 10. *Breakdown material of rockets*

Materials, grams	Average	Max.	Min.
Gross weight	192.0 (100%)	359	80
NEC	56.0 (28.3%)	150	16.6
Paper	84.5 (44.9%)	195.3	34.0
Plastic	15.1 (7.1%)	58.2	0.6
Clay	21.1 (8.5%)	84.4	4.1
Wood	14.4 (10.7%)	34.4	0
Metal	0 (0%)	0	0

Table 11. *Breakdown material of small aerial shells*

Materials, grams	Average	Max.	Min.
Gross weight	573.1 (100%)	606.5	533.0
NEC	123.6 (21.6%)	133.4	116.2
Paper	340.4 (59.4%)	382.4	313.5
Plastic	22.9 (4.0%)	28.4	20.5
Clay	84.3 (14.7%)	98.1	64.3
Wood	0 (0%)	0	0
Metal	0.2 (0.1%)	0.3	0

type. Due to the manufacturing process they did not vary too much, and the materials used were mostly the same as before. There were 9 different samples randomly selected from factories. This type of consumer fireworks was separated into batteries of firecrackers (or firecrackers on strings) and individual firecrackers. Therefore there was a large spread in the results. Besides NEC, the first two main materials were paper, occupying 33.1% by weight and clay, 50.1% by weight. This group of consumer fireworks did not contain wood nor metal materials. However it contained the highest percentage of clay among all types of fireworks. It was envisaged that firecrackers provided simply a noise effect, a bang, which was mainly generated by using clay confinement. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 9.

Rockets

There were 5 different samples randomly selected from factories. Besides NEC, the first two main materials were paper, occupying 44.9% by weight and wood, 10.7% by weight. This type contained the highest percentage of wood among all types, because all the rocket sticks were of wood. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 10.

Small aerial shells

This type of consumer fireworks was small reloadable aerial shells of less than 1.75 inches diameter. They could be repeatedly loaded into a launch tube and fired one after another. The item is commonly available in the American market. Besides NEC, the first two main materials were paper, occupying 59.4% by weight and clay, 14.7% by weight. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 11.

Roman candles

There were 5 different sample randomly selected from factories for this type of consumer fireworks. Besides NEC, the main two materials were paper, occupying 72.4%, and clay, 12.0% by weight. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are also shown in Table 12.

Party poppers

This type of consumer fireworks contained 5 different samples but were all very similar to each other. Besides NEC, the main two materials were plastic, occupying 52.7% by weight and paper, 46.6% by weight. For a detailed breakdown refer to Figure 3.

Table 12. *Breakdown of materials in roman candles*

Materials	Average, grams	Max.	Min.
Gross weight	310.2 (100%)	740	70
NEC	44.3 (13.6%)	107	6.6
Paper	226.2 (72.4%)	544	50.0
Plastic	0 (0%)	0	0
Clay	37.1 (12.0%)	88.5	2.9
Wood	2.0 (1.8%)	1.8	0
Metal	0 (0%)	0	0

Table 13. *Breakdown of materials in party poppers*

Materials	Average, grams	Max.	Min.
Gross weight	127.3 (100%)	354	2.6
NEC	0.3 (0.2%)	0.7	0.01
Paper	61.1 (46.6%)	173	1.0
Plastic	65.7 (52.7%)	180	1.6
Clay	0 (0%)	0	0
Wood	0 (0%)	1.8	0
Metal	0 (0%)	0	0

Table 14. *Breakdown of materials in sparklers*

Materials	Average, grams	Max.	Min.
Gross weight	12.7 (100%)	17.7	1.3
NEC	4.6 (42.6%)	6.6	0.8
Paper	3.1 (19.0%)	6.9	0
Plastic	0.2 (1.3%)	0.8	0.1
Clay	0 (0%)	0	0
Wood	0 (0%)	0	0
Metal	4.7 (36.9%)	9.5	0.5

Table 15. *Breakdown of materials in missiles*

Materials	Average, grams	Max.	Min.
Gross weight	242.7 (100%)	387.6	95.0
NEC	48.2 (20.1%)	70.4	18.5
Paper	48.9 (21.7%)	64.2	23.0
Plastic	139.0 (56.0%)	243.0	53.3
Clay	6.2 (2.1%)	9.6	0
Wood	0 (0%)	0	0
Metal	0 (0%)	0	0

The maximum and minimum weights of material are also shown in Table 13.

Sparklers

This type of consumer fireworks contained 4 different samples. It was the type of consumer fireworks containing the largest amount of metal material. Besides NEC, the main two materials were metal, occupying 36.9% by weight, and paper, 19.0% by weight. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 14.

Missiles

This type of consumer fireworks contains 3 different samples only. Besides NEC, the main two materials were plastic, occupying 56.0% by weight and paper, 21.7% by weight. For a detailed breakdown refer to Figure 3. The maximum and minimum weights of material are shown in Table 15.

Magic whip

This is the only group containing 1 sample only, because such samples are not common. Besides NEC, the main two materials were plastic, occupying 24.2% by weight and paper, 21.8% by weight. A detailed breakdown is shown in Figure 3.

Conclusion

Most of the waste from consumer fireworks consisted of paper and clay materials after functioning which were 44.6% and 20.7% respectively by weight. If only leftover materials were counted (deducting NEC, 20.7%) these two materials occupied 56.2% and 26.1%, a total of 82.3%. Wood occupies 6% and metal occupies 3%. All of them are recyclable easily. Therefore most consumer firework packaging (waste from fireworks) is collected by pickers who sell to recycling facilities, see Figures 4 to 7, for recycling of paper. Plastic is the most arguable material as it depends on which type of plastic it is. The percentage of plastic material is about 9.7% by weight (or 9% by weight of leftovers) among all consumer fireworks. Among these recycling materials, the one with the greatest impact on environmental pollution is plastic material. Most of the plastic found in the study was PVC and PE.

If packaging used more environmentally friendly materials, the percentage of recycling would increase, and it would have less impact on the environment. Some factories have started to develop the use of new reusable materials in the manufacturing of fireworks, such as plastic tubes for reloadable aerial shells or some new materials which are biodegradable in the environment, as shown in Figure 8. As a general trend, manufacturers have become aware of the challenge as well as the opportunity offered by the environmental impact caused by fireworks.

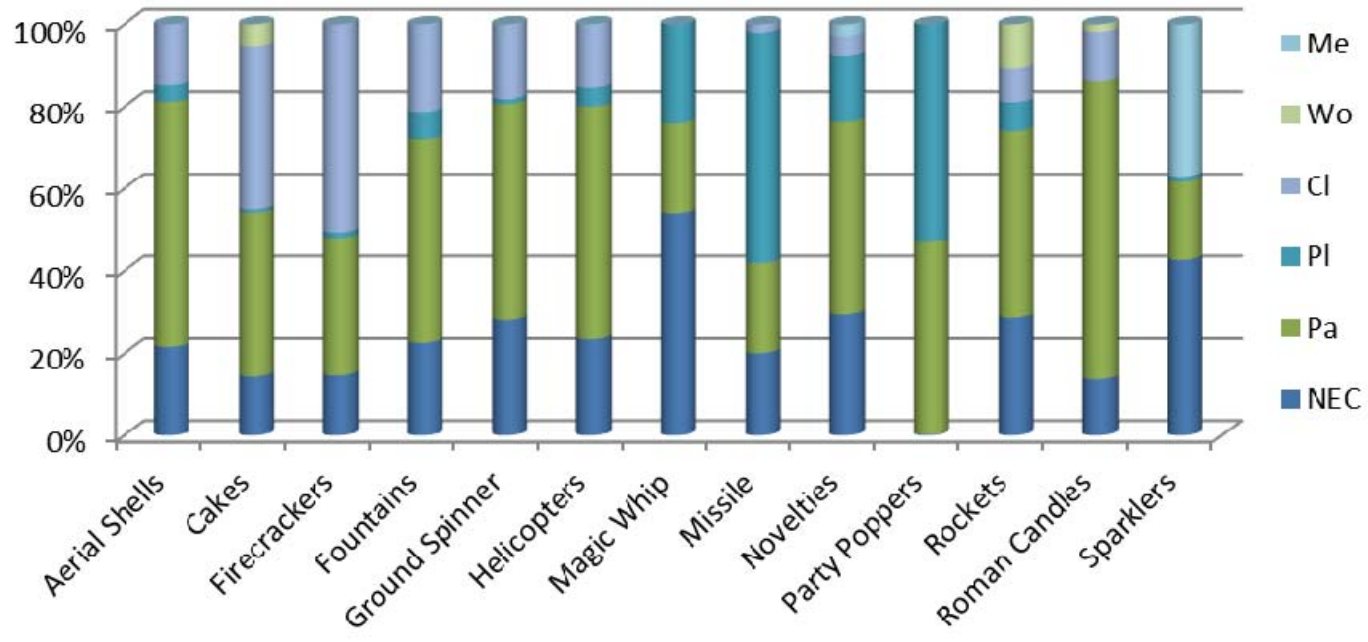

Figure 3. *Material used in different types of consumer fireworks by percentage.*

Figure 4. *Waste fireworks collected in recycling shops in Liuyang City, Hunan, China.*

Figure 5. *Trash paper from different packaging consumer products.*

Figure 6. *Recycling paper by mixing trash paper and fibers before milling.*

Figure 7. *Finished recycled paper.*

Figure 8. *Innovative material to replace paper and clay in manufacturing cakes*

Figure 9. *Some examples of consumer fireworks: (a) missile; (b) helicopter; (c) firecrackers; (d) novelty.*

Table 16. *Breakdown of materials in magic whip*

Materials	Average, grams	Max.	Min.
Gross weight	247.5 (100%)	0	0
NEC	133.8 (54.1%)	0	0
Paper	53.9 (21.8%)	0	0
Plastic	59.8 (24.2%)	0	0
Clay	0(0%)	0	0
Wood	0 (0%)	0	0
Metal	0 (0%)	0	0

References

1. Green Power, Hong Kong, *Survey on Consumption and Celebration Habits during Mid-Autumn Festival*, September 13, 2011.

2. N. J. Lo, *Manufacturing and Safe Management of Fireworks*, Hunan Scientific Technology Publisher, 1987.

3. Andrew Tang, *Recycling of Consumer Fireworks*, 13th ISF Malta 2012.

4. Ronald Lancaster, *Fireworks – Principles and Practice*, 4th edition (2006).

5. Michael S. Russell, *The Chemistry of Fireworks*, RSC Publishing, 2000.