Dragon Tears: a pellet-based design for safe and optimized polysulfide-glitter sparklers

Frederick Van Der Sypt, M.D.

Geitstraat 83, Ghent, Belgium

Frederick.vandersypt@protonmail.com

Abstract: *Polysulfide sparklers are renowned for their delicate spark display and complex reaction dynamics, rooted in the centuries-old Japanese tradition of Senko Hanabi. However, modern challenges such as regulatory restrictions and manual production costs threaten their survival. Recent innovations—including the use of (bi)carbonate-based compositions and the integration of metal powders—have significantly improved safety and visual performance. This study introduces a pellet-based design called the Dragon Tear, which standardizes the sparkler's core composition for better reproducibility and ease of handling. These pellets can be safely stored, transported, and later wrapped in paper by the end user to create a functional sparkler. With added magnesium or magnalium, the design produces a striking glitter effect in the final phase of combustion. The Dragon Tear bridges traditional beauty with modern practicality, offering a scalable, low-risk alternative that preserves the art of polysulfide sparklers for future generations.*

Introduction

Polysulfide sparklers are fascinating in several respects. Their sparkling display is arguably the most refined in the world of pyrotechnics, and their underlying reaction mechanism has been studied for over a century [1-3]. Despite their seemingly simple nature, ensuring reliable performance presents a considerable technical challenge. The earliest generation of polysulfide sparklers, based on sulfur-rich black powder, have been known in Japan for at least 300 years under the name *Senko Hanabi*. However, their continued existence is now under threat due to increasingly strict regulations and the high cost of manual production [4].

While these sparklers are deeply cherished in their country of origin, they remain relatively unknown in the rest of the world. Recently, however, several studies on polysulfide sparklers have also emerged in Western literature [5-8], and a growing number of amateur pyrotechnicians have shown renewed interest in the phenomenon [9,10]. This has led to several innovations in the traditional sparkler design. One was the development of a new type of composition. In 1981, Shimizu demonstrated that the sparkling polysulfide melt could be generated using potassium carbonate instead of potassium nitrate [11]. In recent years, this principle was developed into a functional sparkler using the traditional way of wrapping the loose composition in a paper strip [7,12]. The use of a carbonate-based composition gives these so-called *carbo-hanabi* sparklers a unique place within the pyrotechnic landscape. Since the composition cannot sustain its own combustion, it can be safely prepared, stored, and transported. For the same reason, *carbo-hanabi* sparklers find themselves at the border of the legal definition of a “pyrotechnic article” [13].

Article Details | ***Article No:- 0130***

Manuscript Received:- 06/08/2025 | ***Final Revisions:- 19/08/2025***

Publication Date:- 16/09/2025 | ***Archive Reference:- 2257***

Figure 1: Dragon Tears, suspending the world of glitter in a drop of fire…

A further advancement was made by Cusick, who demonstrated that carbo-hanabi compositions can also be formulated using potassium bicarbonate [14]. This potassium salt is considerably less hazardous and less hygroscopic than the carbonate counterpart, thereby enhancing the suitability of the sparklers for commercial applications.

A third innovation was described in 2013, namely the integration of metal into the polysulfide melt, producing an impressive glitter effect during the final phase of the reaction [5,6] (figure 1). This so-called '*satori'* or 'enlightenment' phase creates a stark and dramatic contrast with the earlier, more subdued 'old age' phase—adding a layer of suspense and intensity.

Choosing an alternative method to initiate the polysulfide reaction through (bi)carbonate does not lessen the surprising complexity involved in creating a high-performing, reliable sparkler. This is largely due to the many construction variables that determine its behavior. The traditional method—wrapping powdered composition in paper—is prone to inconsistencies and heavily reliant on the skill of the pyrotechnician.

This study aims to develop a new approach in which both the quantity and the nature of the *carbo-hanabi* composition are standardized in a reproducible solid form. This form should be easy to finish into a sparkler and allow for efficient large-scale production. As such, the cost and complexity of manufacturing polysulfide sparklers could be significantly reduced.

At the same time, this paper also explores opportunities to improve function and visual effect. Ideally, this new form should be ignitable with any flame type—not just a jet flame, as is currently the case with most *carbo-hanabi* designs. The design should also allow for the safe and effective integration of metals into the melt.

Ultimately, the goal of this research was to safeguard the exceptional beauty of polysulfide sparklers for future generations. Presented below is the result of this research: the "Dragon Tear". Technically, it is a paper polysulfide-glitter sparkler, constructed around a pellet of carbo-hanabi composition and complemented with magnesium or magnalium to trigger the glitter reaction. In other words, 'a *spritzel* on a string [15]'. The name pays tribute to the Dragon of Ghent, which watches since 1377 from atop the Belfry over the city where this design was conceived. The dragon, both graceful and formidable, reflects the elegant spark display and crackling climax of these unique sparklers.

Materials

Potassium bicarbonate

Food-grade $KHCO_3$ was used (Labshop.nl).

Sulfur

Sulfur powder with a purity of 99.95% was sourced from Werth-Metall.

Charcoal

Charcoal was produced from Scots pine (*Pinus sylvestris*, sourced from Gamma). The wood was fully carbonized for 1 hour in a sealed metal container placed in the embers of a wood fire. The resulting charcoal pieces were crushed with a hammer until they passed through a 4 mm mesh. Subsequently, 140 g of this charcoal was milled in the ball mill described below, in three cycles of 10 minutes each. To ensure full homogeneity, the milling jar was opened after each cycle, and any material adhering to the walls was scraped off and mixed back into the powder.

Soot

Soot was obtained by burning soybean oil in small metal containers fitted with wide paper wicks. Aluminum food trays were placed upside down above the flames to collect the soot deposits. Visual documentation of this method can be found in reference [9] at timestamp 51:30. Approximately 40 g of soot was collected per 5 liters of burned soybean oil.

Carboxymethyl Cellulose (CMC)

Food-grade CMC from Saporepuro (GioiaGroup s.r.l.) was used.

Ammoniumbicarbonate

Food-grade ammonium bicarbonate (Koopjesdrogisterij.nl) was used as a processing aid. The particle size distribution was as follows: +40 mesh: 0.1%; 40–50 mesh: 0.2%; 50–60 mesh: 9%; 60–80 mesh: 53%; 80–100 mesh: 28%; 100–120 mesh: 7%; >120 mesh: 2.8%.

Paper

The selected paper was Smoking Thinnest (10 g/m²) on rolls (PaperGuru). Each 4-meter roll was cut into 30 mm wide segments using a scroll saw (Dremel Moto-Saw MS20).

Magnesium

Type LNR52, 300–600 µm, 99.8% purity, passivated using mineral acids (Werth-Metall); sieved to <50 mesh (figure 2).

Magnalium

50/50 Mg/Al alloy, 200–400 µm (Werth-Metall); sieved to >60 mesh.

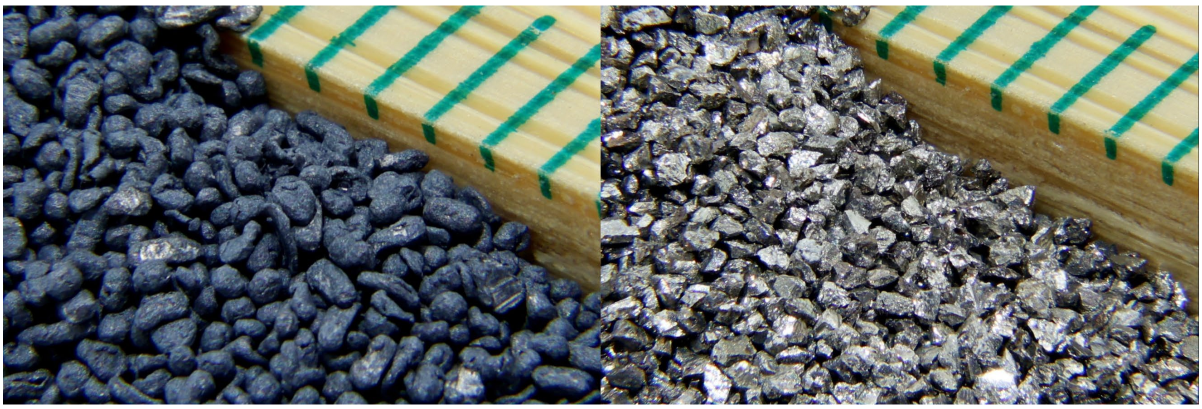

Figure 2: Macro photograph of two high-performing metal types. Left: magnesium (300–600 µm, <50 mesh); right: magnalium 50/50 (200–400 µm, >60 mesh). Scale divisions represent 1 mm.

Ball Mill

Figure 3: 3.6-liter milling jar with 12 mm steel grinding media

Container: 3.6-liter HDPE drum (figure 3) (voertonnen.nl)
Grinding media: Steel balls (12 mm diameter, 1300 pieces, Bogenfreund.de). In the case of Carbo-Hanabi, sparking media may be used, as there is no risk of ignition. The rotation speed of the mill is 65 revolutions per minute.

Extruder

Makin's clay extruder equipped with a 4.5 mm internal diameter washer (alternative: a 50 mL syringe with the washer glued to the top).

Food dehydrator

A WMF Kitchenminis 0415250011 Cromargan dehydrator was used in which warm air is blown upward through a vertical stack consisting of five levels of stainless steel mesh trays framed in plastic. On each level, a 12 × 25 cm non-stick mat is placed to ensure sufficient space around the sheets for smooth and even airflow.

Saw and saw jig

A Japanese pull saw, Dozuki type was used: Kami No Utsuwa (Gyokucho), blade thickness 0.15 mm. A custom-cut saw jig was made using a laser cutter (figure 4). Its construction is detailed in the Appendix (figures 37-41).

Small hardware

30 mesh sieve, woven non-stick oven mats, flexible 700ml plaster mixing cup, Danish dough whisk.

Figure 4: Custom-made sawing guide and Japanese 'Dozuki'-type pull saw

Methods

A. Production of Dragon-Pellets

Base composition for approximately 6,500 pellets:

1. 377.6 g of $KHCO_3$ and 168.5 g of sulfur are sieved through a 30 mesh screen and combined with 26.2 g of soy soot. This mixture is shaken for 2 minutes in an empty 3.6-liter HDPE milling jar.
2. Subsequently, 1.8 liters of 12 mm steel milling balls are added to the jar, and the mixture is milled in a ball mill for three cycles of 30 minutes each. After each cycle, the contents are sieved, and any material adhering to the jar is loosened and reincorporated to ensure homogeneity.

Figure 5: The composition and water are initially mixed using a Danish dough whisk

Figure 6: The paste is then kneaded by hand. After hydration of the CMC, a well-processable paste is obtained.

For the production of 500 pellets:

3. From the base mixture, 45.85 g is weighed and mixed with 4.15 g of charcoal, 30.00 g of NH_4HCO_3, and 750 mg of CMC. This mixture is passed five times through a 30 mesh sieve.
4. The resulting blend is then shaken for 5 minutes using various motions in a well-sealed, empty 500 mL container, followed by another five passes through the sieve.
5. The final composition is transferred to a flexible 700 mL plaster mixing cup, and 18 mL of demineralized water is added.
6. Using a Danish dough whisk, the water is incorporated into the mixture over 2 minutes to ensure homogeneous distribution (figure 5). The resulting mass is then kneaded manually with gloves for 2 minutes into a sticky paste. After a resting period of 5 minutes (to allow for CMC hydration), the mixture is kneaded again for an additional 2 minutes (figure 6).
7. The paste is kneaded into one or more rolls with a diameter slightly smaller than the internal diameter of the clay extruder or syringe. The extrusion opening is formed by a metal washer with an inner diameter of 4.5 mm (figure 7).
8. With consistent pressure, the paste is extruded into strands onto mesh-patterned non-stick mats. If necessary, these strands can be manually aligned with

Figure 7: The paste can be extruded from a syringe with moderate force. However, a clay extruder with a screw mechanism provides easier handling.

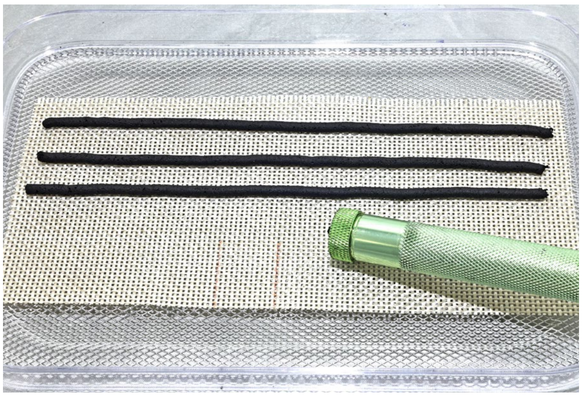

Figure 8: The strands are aligned with the mesh pattern of the oven mats.

Figure 9: The strands placed in the food dehydrator just a few minutes earlier have visibly increased in volume.

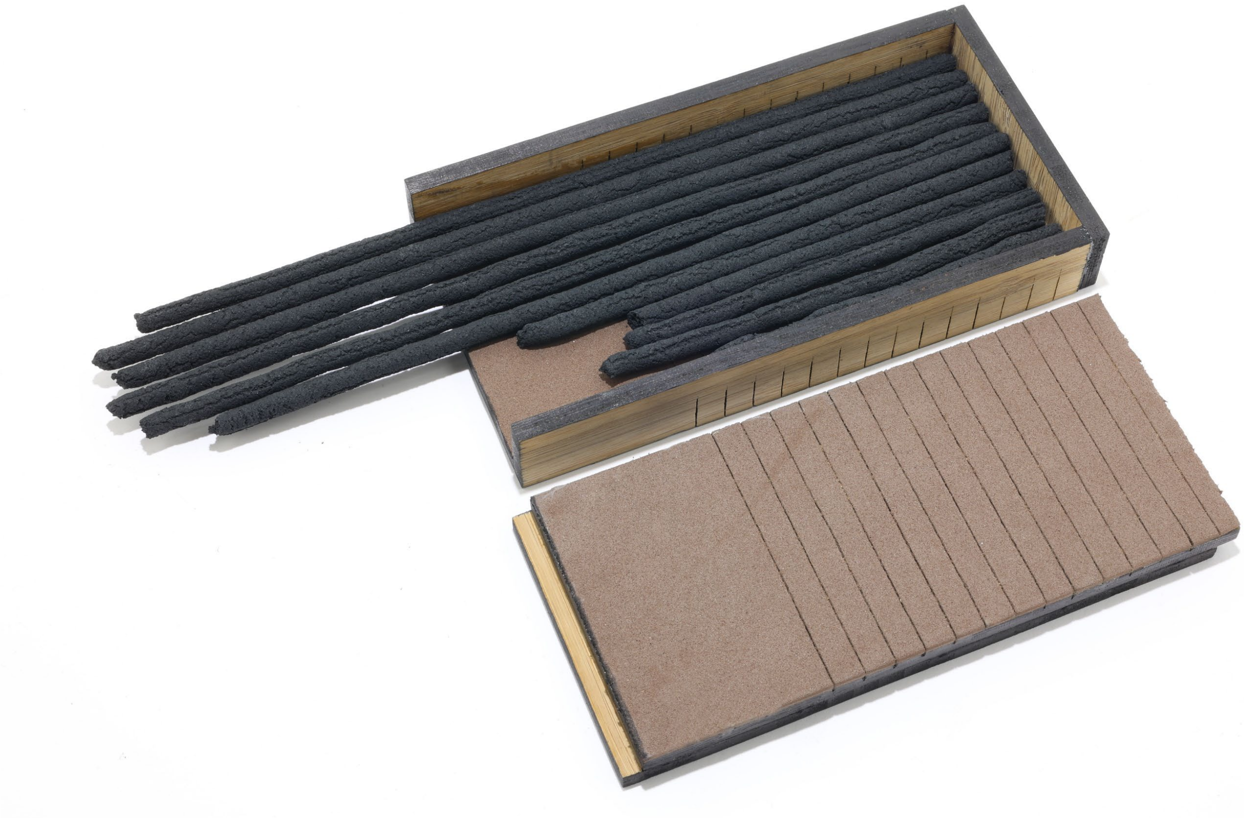

Figure 10: The sawing guide accommodates 12 rods side by side. If fewer rods are to be cut, they should be placed against the side where the longer rods are positioned in this example.

the mesh pattern (figure 8). This amount of composition yields approximately 330 cm of strand.

9. The strands are then dried and partially decomposed in the food dehydrator for 6 hours at 60 °C (figure 9).
10. The resulting rods are arranged side-by-side in a custom-designed sawing guide and are then cut into pellets using a Japanese pull saw, followed by sieving (figures 10-14).
11. For research purposes or maximum reproducibility, the pellets (figure 15) can be further sorted by weight.

Figure 11: The lid is placed on top of the rods, and the entire assembly is inverted.

Figure 12: The rods are then cut into ~7 mm segments using the pull saw, while applying gentle pressure on the sawing guide to lock the rods in place. While Western in origin, the pellet process resonates with the spirit of Japanese tradition.

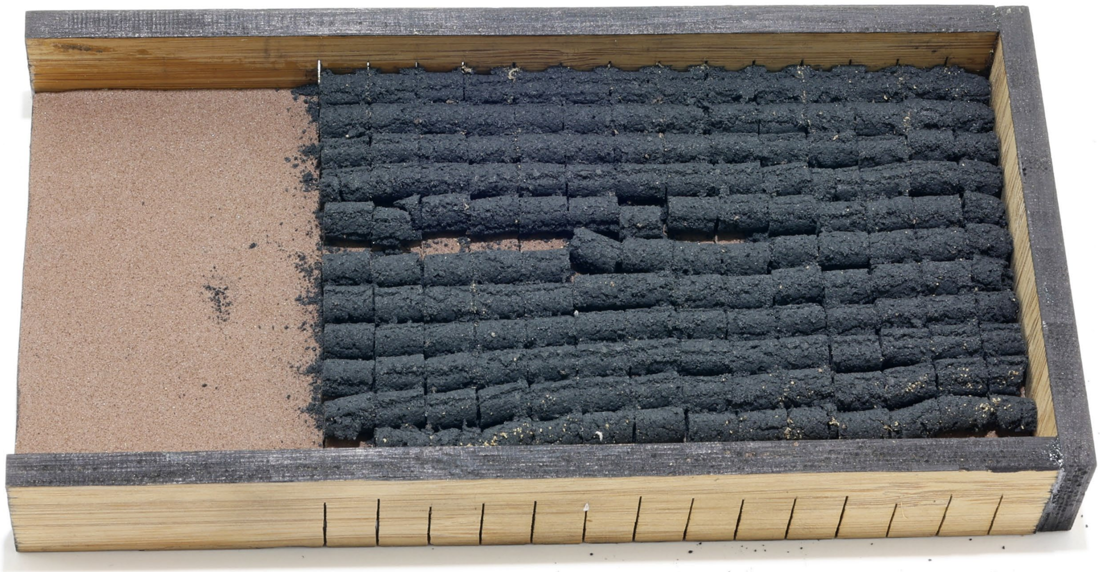

Figure 13: Approximately 150 pellets can be cut at once. The breakage rate is less than 5%.

Figure 14: An adapted coarse sieve is used to efficiently separate the pellets from the sawdust.

Figure 15: The resulting pellets are clean, strong and uniform.

B. Construction of a Dragon Tear (right-handed)

1. A strip of paper measuring 80 × 30 mm is torn off and held with the thumb, index finger, and middle finger of the left hand, forming a groove (figures 16, 17).
2. One pellet is placed a few millimeters from the right end.

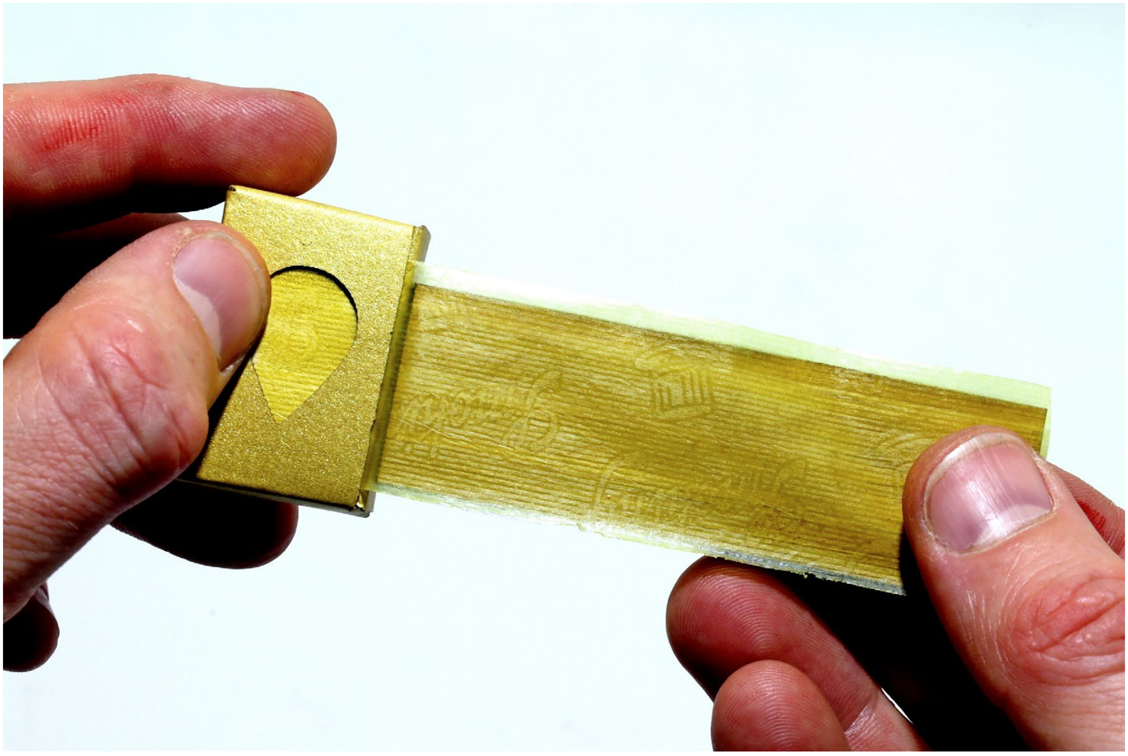

Figure 16: A strip of paper is measured using a piece of wood or cardboard of the correct length and torn off at the edge of the box.

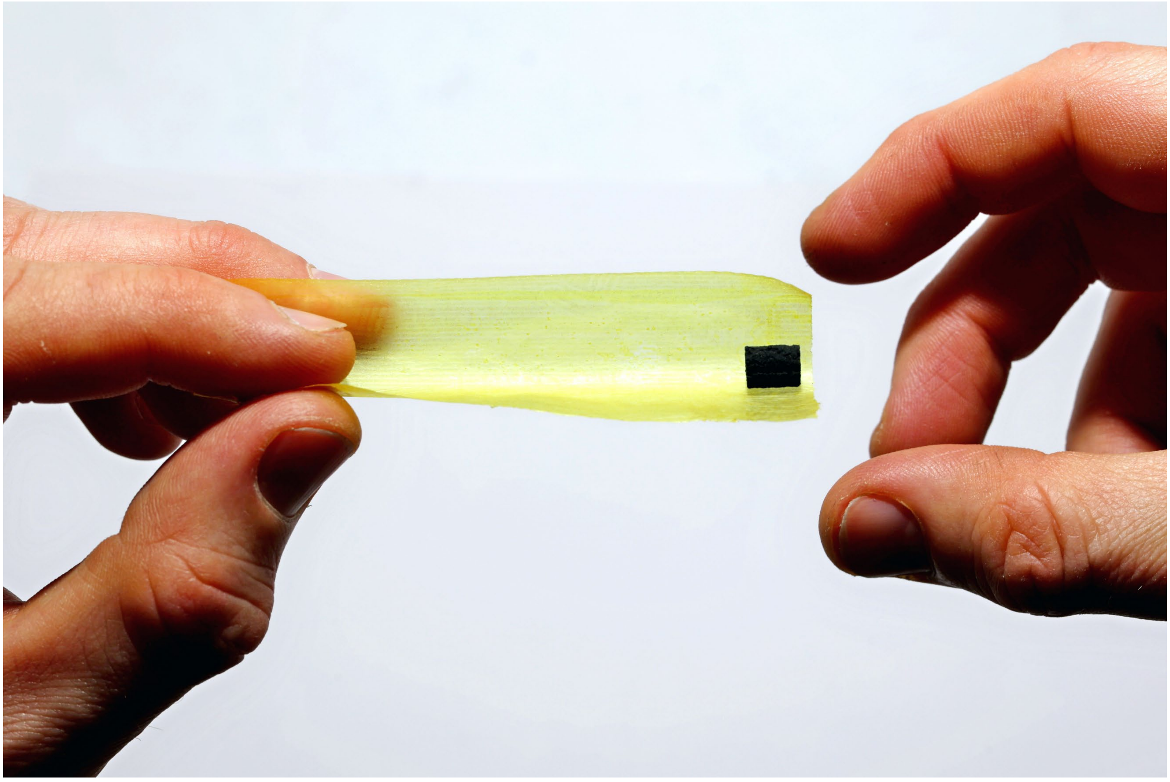

Figure 17: Placement of the pellet on the paper strip.

3. Using the thumb, index finger, and middle finger of the right hand, the paper is now wrapped around the pellet until the paper is pinched just beneath the opposite side. This creates a groove on the left side, into which a few metal particles (2-4 mg) are sprinkled (figure 18).

4. The entire assembly is then tilted 90° to the right, so that all the metal powder

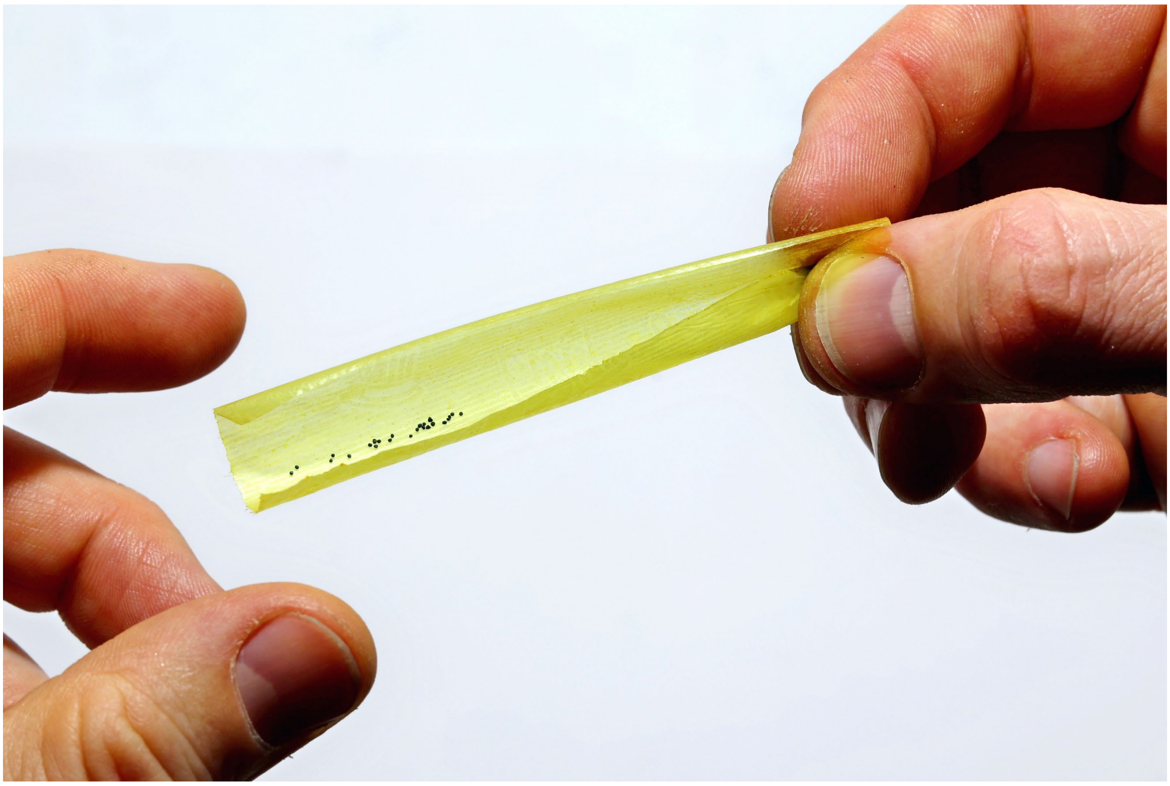

Figure 18: A limited amount of metal is sufficient.

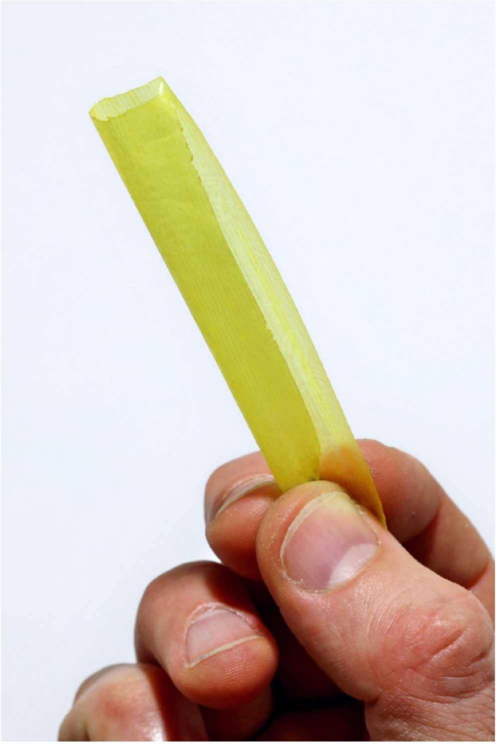

Figure 19: The metal slides along the paper and into the pores of the pellet.

moves against the pellet and partly settles into the cavities. If necessary, the left hand can gently tap the side of the right hand to assist with this (figure 19).

5. The adhesive edge at the level of the pellet is moistened, and with the index and middle fingers of the left hand, the open left side is closed (figure 20). While fully wrapping the pellet with the paper using the right hand, the left thumb ensures that the paper is folded evenly along the edges. This step ends in a position where the pellet is held with the thumb and index finger of the right hand, while the paper is kept taut on the left side with the thumb and index finger of the left hand (figure 21).

6. While securely holding the paper with the left hand and the pellet with the right hand, the paper is pulled tight and the pellet is rolled between the fingers along the underside of the thumb (figure 22).

7. At this point, the middle and ring fingers of the left hand will grip the pellet at the end and keep the paper taut. This allows the right hand to reposition for the next wrap (figure 23). Approximately 6-8 wraps are made until the paper is felt to be twisted between the thumb and index finger of the left hand. The pulling force applied during this entire phase is crucial for the straight form of the sparkler and should be as

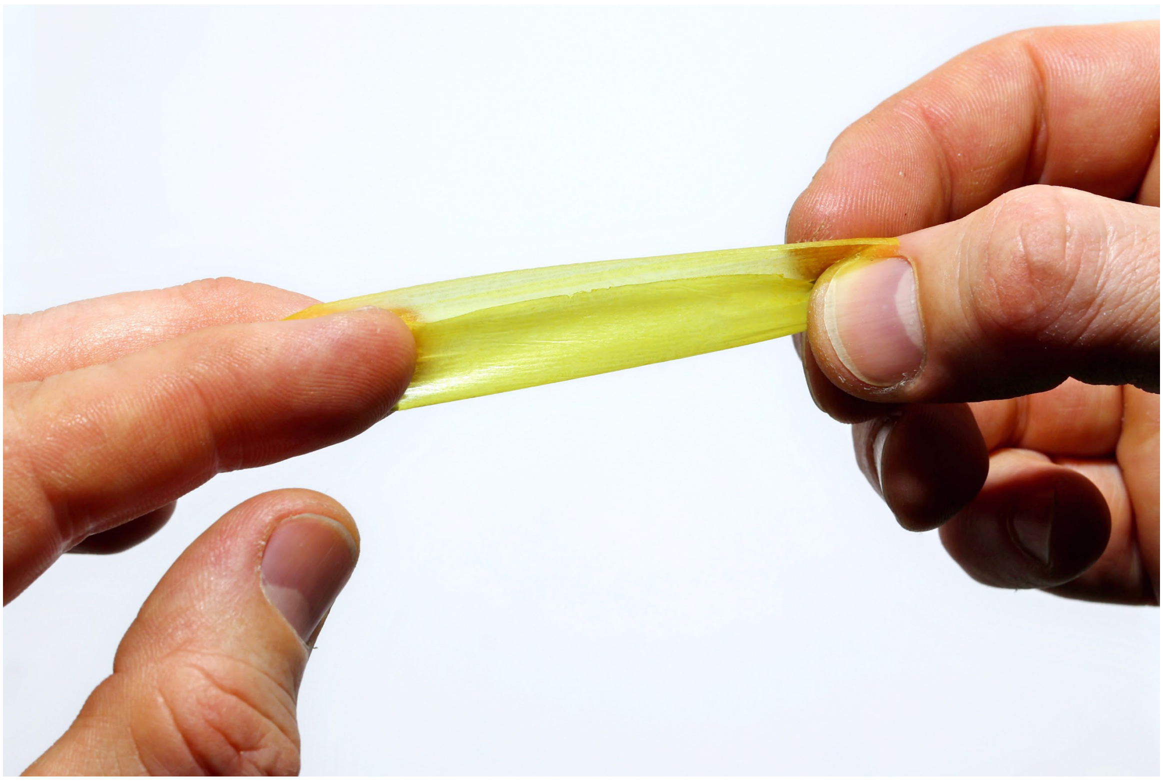

Figure 20: The paper is rolled parallelly. On the right, around the pellet, and on the left, by folding it over itself.

Figure 21: During the rolling, the sparkler is kept facing upwards so that the metal remains in contact with the pellet.

strong as possible without tearing the paper.

8. Subsequently, the thumb and index finger of the left hand release and move towards the pellet. The pellet is then rotated with the right hand, while the paper is kept under tension with the left hand. The paper is twisted until just below the tear point and simultaneously pushed against the pellet, ensuring minimal space

Figure 22: It is important to maintain tension on the paper during the rolling process to ensure a neat, straight finish.

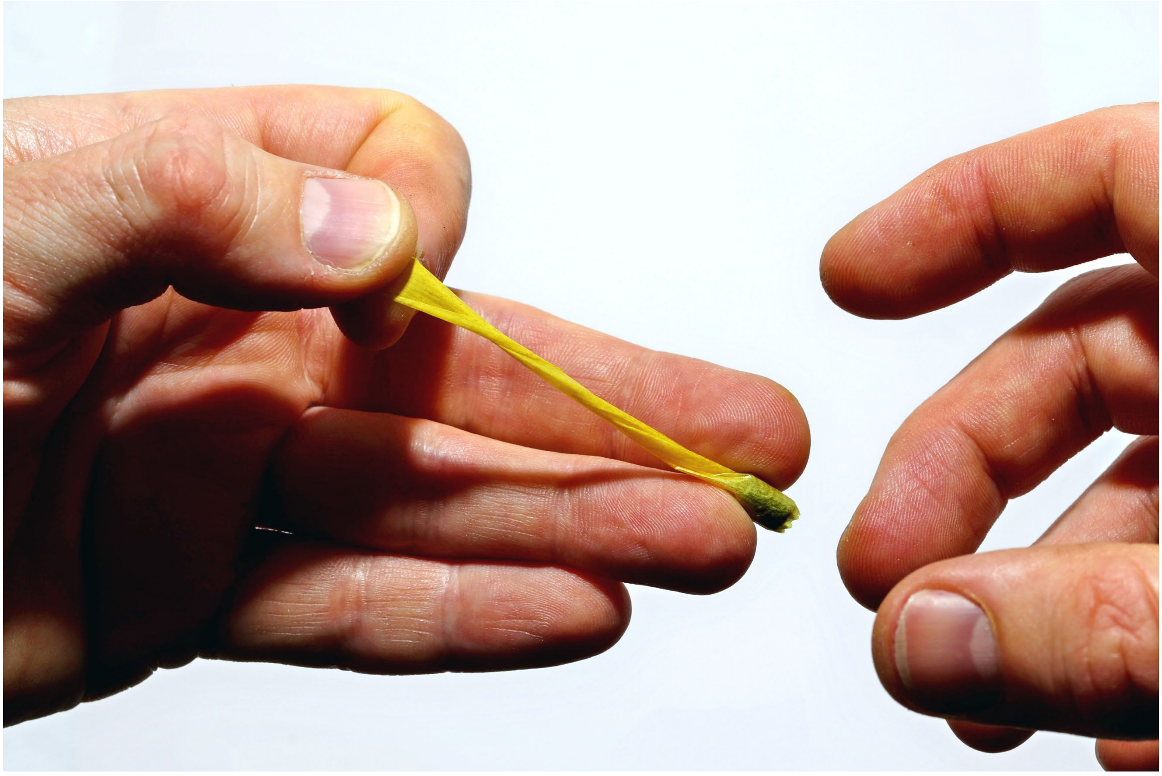

Figure 23: The pellet is secured with the fingertips of the middle and ring fingers, allowing the right hand to reposition for the next wrap.

between the pellet and the twisted paper (figure 24). The left hand then moves slightly and the twisting is repeated with the right hand until just below the tear point. This is done one final time, ensuring that the first 1.5 cm of the stem, the 'neck' of the sparkler, is tightly twisted.

9. The loose paper at the left end is gripped again, and the thumb and index finger of the right hand are placed at the top of the

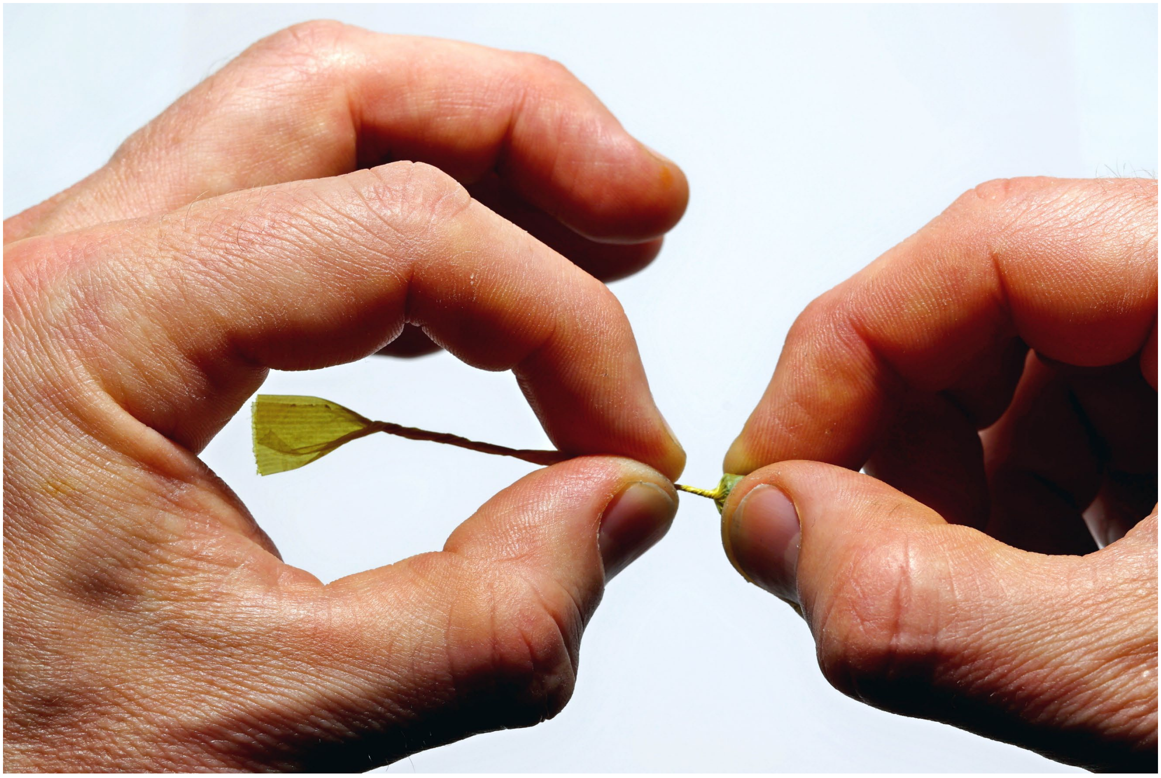

Figure 24: The tight twisting of the neck is crucial for minimizing the risk of falling and ensures a vigorous 'youth' phase.

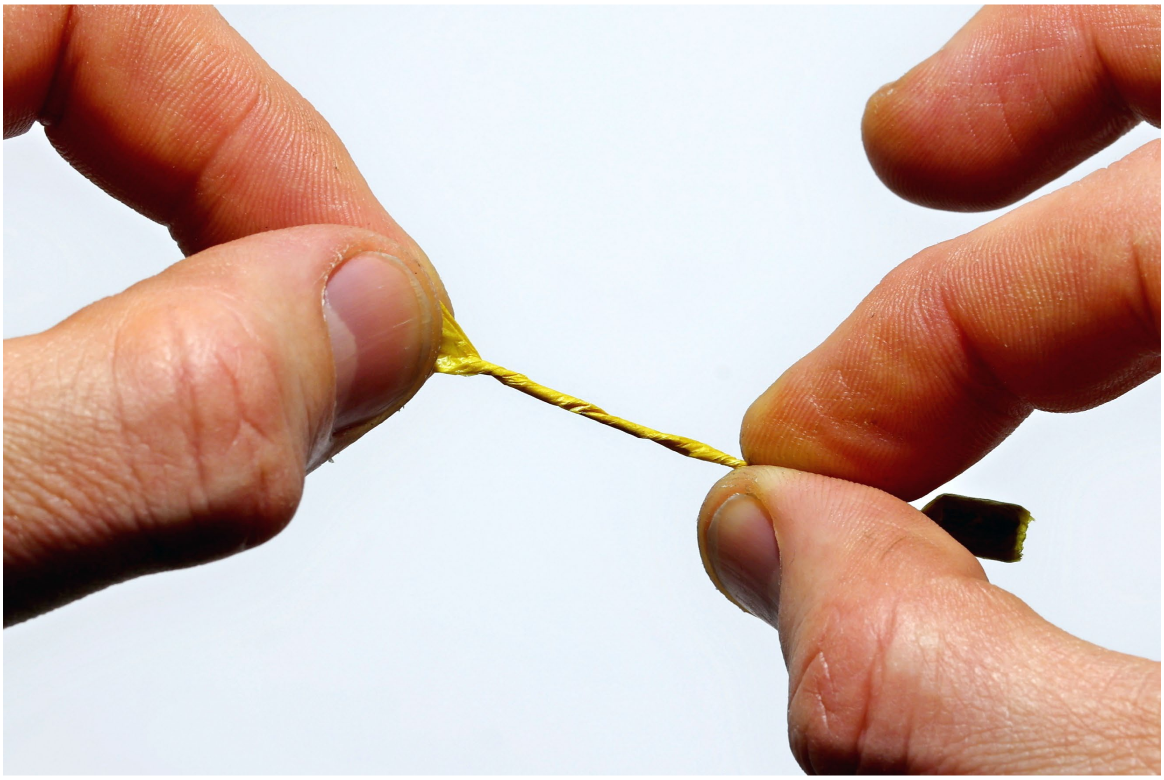

Figure 25: The upper part is also further twisted.

neck. While the paper is pulled tight, these fingers now roll the paper tightly (figure 25). To finish, the fingers of the left hand press the junction of the unwound portion with the stem flat.

10. The Dragon Tear is now complete and can be finished as desired (figure 26).

Figure 26: A finished Dragon Tear. The pine nut next to it weighs exactly the same (112 mg). Even Dragon Tears weighing less than 100 mg can still amaze with their impressive spark display.

C. Method of ignition

1. A location with a fire-resistant surface is chosen, where it is dark, quiet, and windless.
2. The Dragon Tear is held horizontally at waist height of the smallest spectator.
3. The pellet is heated at the end, and throughout the entire heating process, only the most protruding part of the

Figure 27: When using a 'yellow' flame, the pellet is held at the tip of the flame so that it curls around the drop. In this photo, a perpendicular glowing 'jet' can also be distinguished, which is ejected by the drop. This precedes the emission of droplets that form the visible sparks [16]. The surface of the active drop is shiny and reflects the light from the flame.

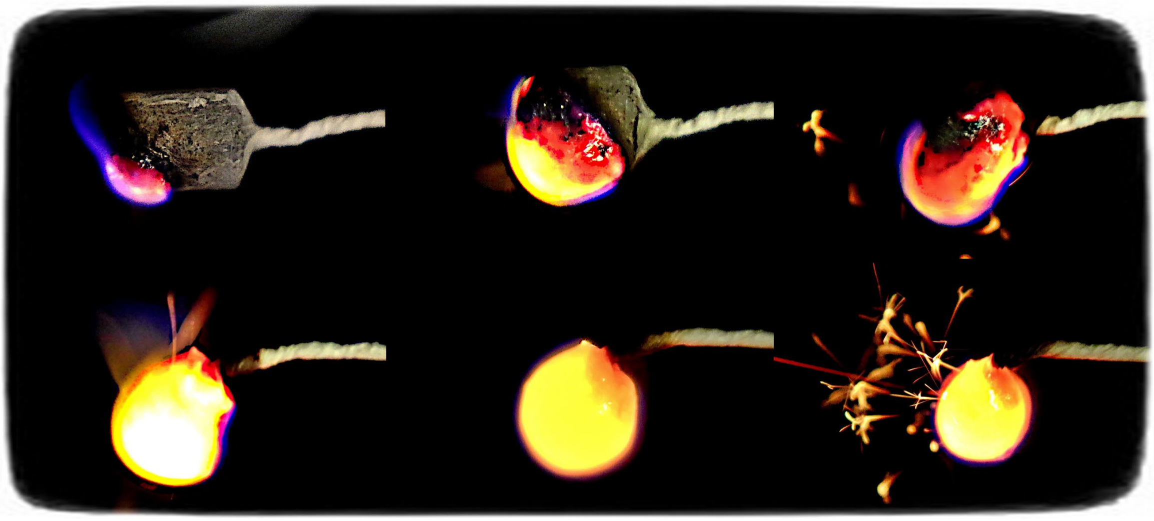

Figure 28: The pellet transforms into a Dragon Tear in several stages: The pellet is heated at the end. The blue flame reveals the high concentration of sulfur; The liquid mass reacts, and its volume increases due to the gases formed; When the last part of the pellet also becomes liquid, the mass tilts; The drop reacts intensely and takes on various shapes. Note the jets on the surface of the drop; The drop contracts into a perfect sphere and hisses loudly; Once long sparks leave the drop, heating is stopped.

forming Dragon Tear is heated. This is done with a candle or yellow gas flame by placing the end of the pellet in the tip of the flame, allowing the top of the flame to curl around the drop (figure 27). When using a storm lighter, the blue jet flame is

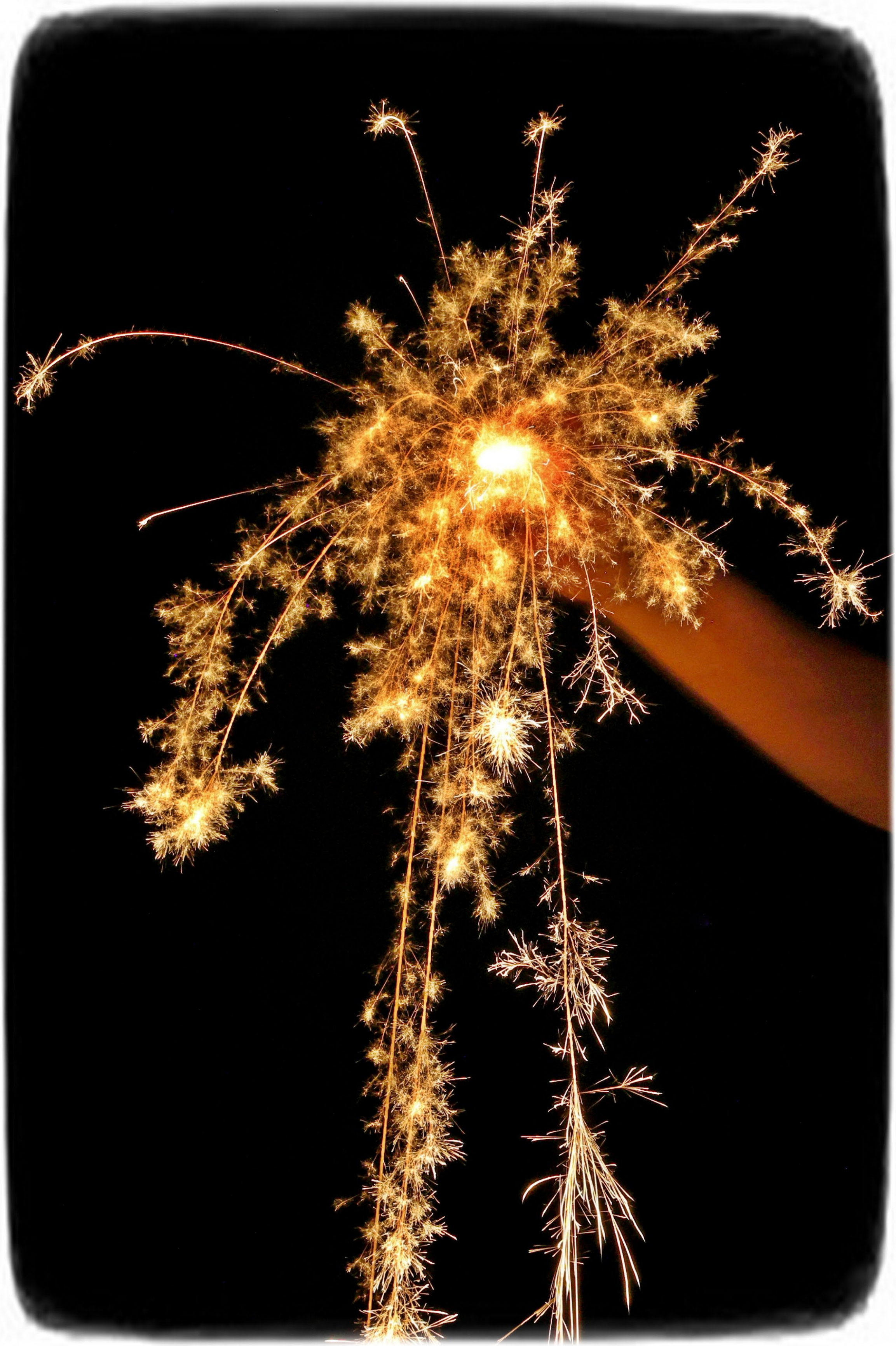

Figure 29: The 'youth' phase of a Dragon Tear is like a bouquet of fire flowers. The refined sparks are harmless to skin and clothing and can travel several dozen centimeters.

Figure 30: It is difficult to imagine that this spectacle originates from a drop of less than 3 mm in diameter. This makes the satori effect all the more surprising and impressive.

directed at the end of the pellet, aiming more at the underside than the top. The flame does not need to make contact with the pellet and can remain several centimeters away. Regardless of the type of flame used, it is important to ensure

Figure 31: A Dragon Tear is shot with a fingernail (right) at the beginning of its youth phase. The spark display fills the entire space with crackling and sizzling sounds.

that the fingers are not positioned directly beneath the forming drop.

4. While heating the pellet, it begins to react visibly and audibly. After about 20 seconds, the bubbling mass tilts, then contracts into a round drop that hisses intensely and begins to emit light (figure 28). Occasionally, a smaller spark may already shoot off. However, heating continues until the first long sparks develop. Also if a premature satori effect occurs, heating is stopped at that point.

5. At this moment, the risk of the drop falling is highest, and it may be necessary to tilt the sparkler slightly upwards so that the drop gets more stem to cling to. On the other hand, the effect is most spectacular when the drop hangs as free as possible at the end of the stem (figure 29). To achieve this, the sparkler is tilted slightly downward.

6. Once the youth phase has passed, the risk of falling is much smaller, and the sparkler can safely be tilted downward. This allows the freely hanging drop to react maximally with the air's oxygen, and the rising temperature can trigger the satori effect (figure 30). Alternatively, one can choose to hold the sparkler more upright, which moderates the effect, but keeps the drop active for a longer period. Sometimes the drop extinguishes, and sometimes it completely bursts apart during the satori effect. If it continues to climb toward the handle, the performance may be concluded by tossing the sparkler upwards in a safe direction. The increased wind speed helps trigger the satori effect at the peak of the arc, causing what seems like a miniature shell-break.

7. An alternative method of use is to heat the Dragon Tear until step 5 and then shoot it through the air with a fingernail (figure 31).

Results and Discussion

The reliable operation of polysulfide sparklers is a significant pyrotechnic challenge. For this study, over 40 variables were investigated and standardized. In the following discussion, we will focus on the choices that were ultimately made. We will follow the chronology of the production process, as well as examine the ignition and the various ways of interacting with the polysulfide drop. Finally, we will briefly address the positioning of this type of firework within European legislation and the economic aspects of this production method.

Raw Materials and Base Mixture

To standardize the composition, it is important to always start with raw materials that have the same physical properties. This includes the moisture content of hygroscopic substances (particularly potassium bicarbonate and charcoal). Therefore, all raw materials used are stored for at least two weeks before processing in containers with breathable lids (Tyvek) inside larger containers where calcium chloride is present as a desiccant.

For this study, various types of charcoal were tested: *Pinus caribaea* Mor. (Pitchpine), *Larix decidua* (European Larch), *Picea abies* (Spruce), and *Pinus sylvestris* (Pine). With the exception of pitchpine, all of these resinous hardwoods proved to be usable. Each type of charcoal produces sparks with its own character, making further studies into other effective charcoal types interesting. For the Ghent Dragon Tears, a specific batch of *Pinus sylvestris* was ultimately chosen due to its overall favorable characteristics for the various reactive stages from 'youth' to 'old age.' The wood was carbonized by heating the container in the coals of a wood stove. The carbonization temperature of the wood could therefore not be specifically determined. Further research could establish the ideal temperature for each type of charcoal. The relatively high carbonization temperature in this study ensures that the produced charcoal is less hygroscopic [17]. The particle size of the charcoal appears to be a very important parameter for the correct operation of the sparklers. With too large a particle size, there are long but infrequent sparks during the youth phase, the middle age is thin, and the drop's reaction risks stopping before reaching the old age and satori phase. With too small a particle size, sparks are frequent but not as long during the youth phase. The subsequent phases then progress more smoothly up to the old age phase. With optimal particle size, there are long sparks during the youth phase, a vigorous middle age, and a prolonged old age phase with reliable activation of the satori effect. In the ball mill described above, the optimal grinding time for the *Pinus sylvestris* charcoal used is 30 minutes. At more than 40 minutes, there is a clear shortening of the sparks, and at less than 20 minutes, the reaction cannot sustain itself sufficiently. The grinding time must therefore be adjusted according to the properties of the ball mill and the type of charcoal.

Cusick [14] found that potassium bicarbonate can be used as a substitute for potassium carbonate. This substitution results in almost no change to the reaction of the drop, and the additional benefits include its non-harmful nature and a higher critical relative humidity. These advantages made this salt the preferred choice for the current study. On the other hand, Xoltri [9] discovered that soot, obtained from the incomplete combustion of soybean oil, is also effective in polysulfide sparklers. Given the widespread availability and low cost of soybean oil, this seems to be a practical alternative to the pyrotechnic soot traditionally derived from turpentine or even from the incomplete combustion of resinous pine wood.

Among all the ingredients, soot poses the greatest potential health risk. Therefore, a dust mask must always be worn during its production and during the creation of the base mixture. Once bound with CMC into pellets, however, the risk is minimal, and the pellets can be considered non-toxic.

The optimal formula was studied using a triangle diagram [18]. The starting composition was $KHCO_3$: 59%, S: 29%, charcoal: 8% and soot: 4%. Around this formulation, six different points on the diagram were determined and tested. Afterward, another six points were chosen near the best-performing composition, this time closer to one another. The best performer from this second set was selected. The ratio of charcoal to soot was also explored. From these tests, the following conclusions were made: if the total amount of carbon (charcoal + soot) exceeds an optimal threshold (in this study, 14%), the reactivity noticeably decreases. Additionally, if the soot-to-charcoal ratio increases, fewer sparks are generated during the heating phase, the sparks in the youth phase are longer, and the metal is better protected. However, this also results in a general decrease in the drop's reactivity. Based on these findings, the optimal formula was determined as follows:

Figure 32: Macro photograph of several pellets. These have an average diameter of 5.6mm and are approximately 7.3mm long. In the formula, CMC ensures the shape retention of the strands and dried pellets, while ammonium bicarbonate creates the foam structure.

Ingredients:

Potassium Bicarbonate	**596**
Sulfur	**266**
Charcoal	**82**
Soy Soot	**41**
Carboxymethylcellulose	**15**

Processing aids:

Ammonium Bicarbonate (decomposes)	**600**
Demineralized Water (evaporates)	**350**

The method by which this composition is produced is also of great importance. As already discussed, the particle size of the charcoal is crucial for the effect. To standardize this accurately, it is therefore best to grind the charcoal separately. However, there is another reason why it is not desirable to grind all the ingredients at once. During the research, it was found that grinding the potassium bicarbonate, sulfur, and soy soot very finely together ensures that, during the heating phase, the metal particles present in the droplet are better protected from premature activation by a jet flame. Previously, pure magnesium would react during the heating of the pellet, and the satori effect could only be obtained if the pellet was heated with a candle or yellow gas flame. Because the grinding time of this base mixture is much longer than the optimal grinding time for the charcoal, these processes must therefore take place separately. An additional advantage of this is that smaller test batches can be made with different types of charcoal.

The CMC powder is also only added in a second phase to minimize sticking and clumping effects during grinding and storage of the base mixture. During the research phase, several binders were tested: gum arabic, xanthan gum, rice starch, carboxymethylcellulose (CMC), and combinations of these. It was found that CMC plays an important role in keeping the ingredients in suspension, thus ensuring a uniform composition. CMC also allows the viscosity of the suspension to be adjusted so that it is easily extrudable while maintaining its shape. The other binders, which were expected to provide the final hardness of the pellets, caused sparks to be triggered during ignition, which blocked the gas openings of storm lighters. When these binders were omitted, this problem was not only solved, but it also became apparent that CMC on its own is a sufficiently strong binder to provide the pellets with enough hardness, even at relatively low concentrations. It was found that 1% did not provide sufficient hardness to the pellets, and that 2% began to negatively affect the reactivity of the pellets. Therefore, the final concentration was set at 1.5% of the total dry mass. In combination with the limited amount of water, this leads to a CMC solution with a concentration of more than 4%, which is very difficult to prepare without clumping and later difficult to homogenize with the dry mass. Therefore, in this study, the decision was made to pre-homogenize the CMC powder with the dry composition and add the water to it.

The final ingredient, ammonium bicarbonate, is also added only after the grinding process. The use of ammonium bicarbonate is a particular feature of this type of pellet. In the early stages of the research, the metal was initially processed into the base composition without ammonium bicarbonate. Although the metal was protected with linseed oil, part of it decomposed during processing and drying, and the release of hydrogen gas caused the formed strands to foam. This resulted in the pellets becoming wider, and the polysulfide droplet having a larger surface area to adhere to during the heating phase. To further explore these unexpected advantages, alternatives were sought to introduce volume into the finished pellets. Ammonium bicarbonate is a common leavening agent and has the interesting property of decomposing completely into gases and water at a relatively low temperature. The decomposition temperature of 60°C used in this study ensures a rapid and complete breakdown of the ammonium bicarbonate, remaining well below the decomposition temperature of potassium bicarbonate (100°C). The current production process leads to a short rising phase at the start of drying, after which the ammonium bicarbonate in the rods further decomposes over the following hours, leaving an airy foam structure. Attempts were also made to create rods without the foam structure, but the same optimally functioning mixture in this case already emits sparks during heating that block the gas openings of storm lighters. The middle phase also produces fewer and more bushy sparks, and the droplet more easily stops reacting. One open avenue for research is to explore whether an adjustment of the composition can circumvent these limitations.

The formation of a foam structure offers several advantages: first, the pellet has the optimal diameter relative to the width of the paper. This ensures that the pellet is wrapped sufficiently but not too much, which would negatively affect reactivity. Additionally, the foam structure allows the forming droplet to have a larger surface area to adhere to, and it enables the metal particles to settle in the openings, thus providing extra protection against the flame. During the research, it was found that the particle size of the ammonium bicarbonate is crucial for the proper shape, uniformity, and sawability of the rods. For this reason, the ammonium bicarbonate is added without further grinding. Therefore, an analysis of the respective particle sizes was included in the description of the reagents.

Production of pellets

The amount of water added needs to be experimentally adjusted to the specific composition and processing method. A wetter mixture tends to stick more but is easier to press into strands than a drier paste. However, adding too much water leads to irregularities in the shape and homogeneity of the rods.

On a small scale, a clay press or syringe can be used. The screw mechanism of the clay press is more convenient for forming the relatively thick paste into rods. On a larger scale, automatic caulking guns or pasta extruders could be used. An additional advantage of an automated system is that the consistency of the rods can be maximized, leading to even more consistent performance of the sparklers. The current reproducibility via manual processing is already sufficiently high that the sparklers are effective without weighing. A batch of 142 pellets produced according to the described method was weighed and had an average weight per pellet of 87.44mg with a standard deviation of 3.475mg (figure 32). The diameter of the sealing ring determines the final diameter of the pellet, and experimentally, 4.5mm was found to be optimal. A diameter that is too small makes the rods more fragile and results in more paper around the pellet, which negatively affects ignition. A diameter that is too large makes it more difficult to wrap the paper around the pellet and complicates the connection of the neck to the pellet, increasing the risk of the droplet falling off.

The rods are best dried on a non-stick mat with a perforated structure to ensure rapid and even rising, drying, and decomposition. In the above method, a small food dryer is used, in which more than 600 pellets can be produced at a time. This step is also well-suited for scaling up with larger models of food dryers.

At 60°C, the rods are stable in weight after about 4 hours. However, some margin should be allowed, especially when larger quantities are dried simultaneously. After drying and the decomposition of the ammonium bicarbonate, the rods are sawed. An attempt was made to work with an electric scroll saw, which also cuts the paper rolls. However, the up-and-down sawing motion causes frequent breakage of the pellets. It was decided to develop a sawing aid for use with a Japanese Dozuki hand saw with a blade thickness of just 0.15mm. Although this step is still manual, it can quickly produce a large number of pellets. The breakage percentage is under 5 percent. The use of a Japanese pull saw is effective and nicely reflects the traditional roots of these sparklers, but a thin wire saw could also be used for this step.

The length and thus the weight of the pellets are determined based on the optimal ratio between effect and the likelihood of the droplet falling. This must be adjusted based on the type of paper used and the rolling method. Experimentally, it was found that impressive sparklers that go through all phases smoothly can be made with pellets weighing between 75mg and 95mg. The finished and sieved pellets are dust-free and therefore very consumer-friendly to be used in a home setting to create Dragon Tears. They are stable and can be perfectly stored in an environment with normal relative humidity (40-60%). The pellets were also stored for several days at a constant humidity of 75% above a binary mixture of solid sodium chloride in its saturated aqueous solution. The pellets maintained their shape but were found to be compressible during rolling. Therefore, they are best stored in an airtight container, either in a container with a silica gel packet. All carbo-hanabi items can also be safely stored in glass, thus completely avoiding the use of plastic.

Satori-effect

Both the type and particle size as well as the physical form of the metal used have a decisive influence on the satori effect. These types of sparklers thus serve as a laboratory for studying the variables of the glitter phenomenon. The metals already found to be effective for this purpose are pure magnesium and magnalium 50/50. Other magnesium and aluminum alloys were also tested. For this, pure magnesium and magnalium were amalgamated in a small container in a hot coal fire (BBQ starter). After cooling, the different alloys were reduced by striking or drilling. The tested powders proved to offer no advantages over commercially available 50/50 forms. This may be due to the shape of the metal particles, which is also a determining factor for the commercial variants. This is intriguing, as the metal is liquid at the common reaction temperature (>800°C).

During the trials, various types of magnesium and magnalium powders were tested: magnesium 100-200µm, 150-250µm passivated, 150-600µm passivated, 200-400µm, 300-600µm passivated, and 400-1500µm; magnalium 50/50 63-125µm, 100-200µm, 200-400µm, and 400-1500µm. Smaller particle sizes already produce small flashes during the youth phase and tend to react simultaneously in one cluster during the satori phase. Large particles can be activated during the heating phase and sometimes do not react in the later old age phase. The ideal particle size seems to be between 200-400µm. Pure magnesium leads to a unique type of conical spiral sparks, for which no literature could be found. This may be because magnesium does not survive long enough in a typical glitter formula for use in stars or fountains. It is the shielding by soot, the absence of airflow, and the controlled temperature that seem to keep the magnesium protected in the polysulfide droplet. In that sense, Dragon Tears offer an insight into the world of glitter effects that can extend beyond the typical spritz patterns seen in larger fireworks displays. These curled "dragon sparks" leave a unique impression on the retina of the spectators and are a

Figure 33: "Dragons aren't real, but their Tears are." – The conical helix-sparks are a unique feature of these magnesium-based 'spritzels on a string'.

spectacular subject for photography (figures 33, 35). The use of magnesium also creates an impressive crackling sound. In specific cases, the satori reaction with magnesium is even such that the droplet explosively bursts, comparable to a bismuth dragon egg. This occurs only in the old age phase when the droplet falls.

Further research could explore other effective metal alloys and forms or combinations of different types. The metal powder can be conveniently stored and dosed with a plastic PCR-tube, which hermetically seals and can be opened and closed with one hand.

Construction and Finishing

For the finishing of the sparkler, the type and size of the paper used are very important. Not only does the paper serve a structural function, but during the reaction, it is also consumed and thus acts as a reagent in the reaction. Various types of very thin paper were tested, with 'Smoking Thinnest' proving to be superior. It has a weight of 10g/m² and high tensile strength. Furthermore, it is available in rolls of 4m length, which can be cut to the correct width of 30mm using an electric scroll saw. The width of the paper must be carefully chosen. The narrower the paper, the more reactive the droplet is when ignited and the more smoothly it passes through the various phases. However, the risk of the droplet falling increases, and the sparkler may struggle to remain upright. The length of the paper is chosen depending on the intended application. If one wishes to have the sparkler last as long as possible, a longer strip of 10cm is best. If the sparkler is to be thrown in the air during old age to trigger a satori break, the paper can be slightly shorter, for example, 7cm. If the droplet is to be shot off before it reaches old age, the strip can be even shorter.

Equally important is the way the paper is wound. The most crucial area is the neck, just like in the traditional senko hanabi variant. This section must hold the droplet when it is at its largest, heaviest, and most active. Tests show that it is not so much the thickness but the compactness of the neck that is decisive for this ability. The more compact the wound section, the longer the droplet takes to consume it. Because less paper needs to be "processed" by the droplet, it can heat up more by reacting with the surrounding air oxygen, which results in a more intense youth phase with a more beautiful spark display. Optionally, one can apply some collodion to the finished sparkler, rub it over the neck, and dry it quickly in a warm air stream. This method can fix the neck in an optimally compacted state for transport. This minimal amount of collodion does not significantly affect the functioning of the sparkler. However, it does affect the safety profile by introducing a very limited amount of flammable substance.

The paper can be colored, but some types of ink make the sparkler less reactive. Most alcohol-based inks seem to work. For example, Staedtler Lumocolor is available both in marker form and as a solution. The latter can be applied with a wide refillable marker to color the entire strip, or individual markers can be used in combination to create specific color effects. One can also choose to apply color effects after the sparkler has been constructed. This can be done, for example, with a cotton swab or with a glove that has a piece of fabric attached at the fingertip.

At the end of the stick, one can choose to apply a drop of water glass just below the handle. This stops the ascending droplet and prevents combustion. Alternatively, the end can be completely wound as a stick, after which a handle made of thick paper is glued on (using water glass). The pellet design allows the consumer the option to choose their own creative finish or opt for a quick, minimalist construction method for immediate use. In this case, a finished sparkler can be comfortably rolled in less than 40 seconds, which is shorter than the duration of the effect which is exceptional within pyrotechnics.

The Ignition

The elegant spark display and the bubbling, hissing, and crackling sounds that accompany it are best appreciated in a sheltered, dark, and quiet place.

Polysulfide sparklers may be the most interactive form of fireworks because the effect is influenced by multiple variables during ignition and reaction. This is especially true for carbo-hanabi because the duration and method of heating the droplet is an independent and important variable. Unlike previous designs, these pellet sparklers can be ignited with all types of flames, further increasing their usability. They can be ignited both by a candle or yellow gas flame on one

Figure 34: The delicate and refined 'old age' phase resembles the break of a willow-shell.

hand and by a jet flame on the other. Both methods have their advantages and disadvantages. A yellow flame is more readily available, and when heating, the metal is usually not activated, even magnesium. A yellow flame also causes less charcoal to react during the droplet formation. This delays its combustion, and longer sparks occur during the youth phase. A disadvantage of both candle and yellow gas flames is that the environment must be completely windless to properly heat the pellets. Jet flames, on the other hand, are more resistant to wind, which makes it easier to ignite the sparklers in a wider range of conditions. However, this is not always beneficial, as wind along the droplet causes earlier activation of the charcoal and metal, leading to shorter sparks in the youth phase and premature satori effects. These latter effects can, however, be significantly reduced by the prolonged grinding of the soy soot with sulfur and potassium bicarbonate, as discussed earlier. Even when a jet flame is used in a windless environment, the stronger gas flow causes it to generate its own wind and associated effects. Nevertheless, the higher power of this type of flame can quickly bring the droplet to a high temperature, causing it to react strongly and impressively. A clear advantage of jet flames is that they produce a low light output, allowing the eyes to remain more sensitive to the subtlest sparks from the Dragon Tear. Conversely, they generate a roaring sound that drowns out the interesting buildup of bubbling, boiling, and hissing sounds from the forming droplet. Finally, jet flames can easily be directed, so the fingers do not need to be directly under the droplet. If one prefers to ignite Dragon Tears with a yellow flame, pipe lighters can be useful as their flame exits sideways, automatically keeping the fingers away from the droplet. These pellet-based sparklers perform excellently in calm conditions, in contrast to previous designs where additional airflow in the form of wind or blowing was necessary to allow all phases to occur. The current design therefore offers added safety, as it discourages the temptation to blow on the droplet from close up.

The tilt of the sparkler during ignition and reaction is a variable that offers significant control over both the visual effect and the risk of droplet detachment. A Dragon Tear provides the most impressive spectacle when the droplet has minimal contact with the paper strand. This can be achieved by tilting the sparkler slightly downward. To prevent the droplet from falling in this position, it's crucial to tightly wind the neck and to respect the maximum weight.

Conversely, the risk of droplet detachment can be significantly reduced by tilting the sparkler slightly upward, similar to the traditional “stick-type” version of polysulfide sparklers, which are made by binding and drying the composition onto the tips of grass stems. The downside of this orientation is that gravity causes the droplet to adhere to the paper below, consuming it and thus losing reactivity. This makes the youth phase less exuberant.

A logical starting angle is therefore horizontal, allowing for adjustments based on the droplet's behavior. After the youth phase, it is generally possible to tilt the sparkler fully vertically to intensify the subsequent phases. However, if the goal is to extend the duration of the sparkler’s activity, it is better to keep it horizontal to spread the reaction over time. Loosening the paper slightly also causes the sparkler to consume it more quickly, thereby tempering the reaction.

During the old-age phase that follows (figure 34), tension builds and culminates in a surprising glitter finish. This phenomenon is all

Figure 35: Dragon Tears are a rewarding subject for photography. Many images reveal previously unseen spark types, such as this brilliant comet.

Figure 36: At this moment, carbo-hanabi sparklers are not yet commercially available anywhere in the world. To spark interest in this concept, a few sample sparklers are shown here, finished with the logo of PyroGanda, a fictional fireworks company based in Ghent. The sparklers displayed differ in the nature of their satori effect and reflect characteristics of the Ghent Dragon:

**Type '*Elegant*' (yellow)*: magnalium 100–200 µm, subtle glitter accents*
**Type '*Playful*' (blue)*: magnalium 200–400 µm, full-fledged but controlled satori*
**Type '*Fierce*' (red)*: magnesium 300–400 µm, impressive dragon sparks and crackles*

All sparklers shown—including their handles—weigh a combined total of 1237 mg.

the more impressive considering the tiny size the droplet has by that point.

Legal and Economic Aspects

What sets *carbo-hanabi* apart from other types of fireworks is that it challenges their strict legal definition. According to European legislation [13], a *pyrotechnic article* is defined as: "any article containing explosive substances or an explosive mixture of substances designed to produce heat, light, sound, gas or smoke or a combination of such effects through ***self-sustained*** exothermic chemical reactions."

The fact that *carbo-hanabi* relies on atmospheric oxygen for its exothermic reactions may provide it with a privileged position in the context of increasingly strict regulations. Therefore, it is desirable that further research should subject carbo-hanabi sparklers to the appropriate test series in order to consolidate their safety and classification [19].

These *Dragon Tears* also address the financial bottleneck inherent in traditional designs. Rolling them requires less manual skill and can therefore be entrusted to the end user, who gains full freedom and creativity over both the finishing and the visual effect (figures 36). The pellet production process lends itself well to scaling, and combined with the low cost of raw materials, this could result in an accessible market price.

Conclusion

This research has successfully created a high-performing sparkler based on a non-oxidizing, non-toxic composition. The pellets used as the core can be produced on a large scale and are easy to assemble into a reliable sparkler—even by the end user. The sparkler can also be ignited with any type of flame. With this design, the main limitations of current polysulfide sparklers are effectively overcome. Moreover, by integrating magnesium or magnalium, an impressive glitter phase can be added to the sparkler. Many avenues for further research remain open, but with the realization of this *Dragon Tear*, *carbo-hanabi* sparklers appear to have outgrown the laboratory—ready to introduce a wider audience to their safe and refined beauty.

References

1. U. Nakaya and Y. Sekiguti, A physical investigation on sparks of senko hanabi, a miniature firework, *Institute of Physical and Chemical Research*, Tokyo, 1927

2. C. Inoue, Y. Izato, A. Miyake, M. Koshi, Bubble growth in non-evaporative drops of "Senko-hanabi", *Sci. Tech. Energetic Materials,* Vol. 80, 2019

3. C. Inoue, Y. Izato, A. Miyake, E. Villermaux, Direct Self-Sustained Fragmentation Cascade of Reactive Droplets. Physical Review Letters, 2017

4. B. Cusick, *A Japanese Master Craftsman Taught Me To Make Senko Hanabi Fireworks*, https://www.youtube.com/watch?v=yvoUYEu3o-c (accessed 28/04/2025)

5. F. Van Der Sypt, 'Senko hanabi: a study of factors affecting construction and performance', Journal of Pyrotechnics, Issue 32, 2013

6. F. Van Der Sypt, 'The Senko Hanabi Sparkler: a Study of its Reaction Mechanisms', Journal of Pyrotechnics, Issue 32, 2013

7. F. Van Der Sypt, 'Polysulfide sparklers revisited: a practical introduction to Carbo Hanabi', Journal of Pyrotechnics, 2022 (1-14)

8. B. Sturman, 'Real Fireworks with No Pyrotechnic Composition?', Fireworks ISSN 0264-9780. 2022

9. B. Cusick, DIY Fireworks From Kitchen Ingredients (mostly): Senko Hanabi Masterclass, https://www.youtube.com/watch?v=2li1VhaLjXQ&list=PL1a2HkcVbmAVW5LBBThCdHPD3BKDd03Tj&index=9, (accessed 28/04/2025)

10. M. Anticole, Japanese Senko Hanabi Sparkler Contest, ROUND ONE, https://www.youtube.com/watch?v=7Bw5EEm-UCE&list=PLoDcIufsMwofl4SwtyhxQjU6dFXDfhTrH (accessed 28/04/2025)
11. T. Shimizu, Fireworks, the Art, Science and Technique, Pyrotechnica Publications, 1981
12. T. Seki, A Non-Explosive Senko-Hanabi (2017), http://www.kagakunosaiten.jp/convention/pdf/2017/022.pdf (accessed 28/04/25)
13. Directive 2013/29/EU of the European Parliament and of the Council of 12 June 2013 on the harmonisation of the laws of the Member States relating to the making available on the market of pyrotechnic articles (recast) Text with EEA relevance, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013L0029 (accessed 28/04/2025)
14. B. Cusick, 'The World's First non Flammable Fireworks (a novel way to make Senko Hanabi Sparklers)', https://www.youtube.com/watch?v=O3-ucafl1MY, (accessed 28/04/2025)
15. L. S. Oglesby, Glitter, The Chemistry and Techniques, 2nd edn, American Fireworks News, 1989
16. C. Inoue, Chihiro, High Speed Visualization Measurement of Sparkling Fireworks. Journal of the Visualization Society of Japan. 35. 8-13. 10.3154/jvs.35.137_8, 2015
17. A. Francisco et al., Hygroscopicity of charcoal produced in different temperatures, Cerne 22 (4), Oct-Dec 2016, https://doi.org/10.1590/01047760201622032175 (accessed 28/04/2025)
18. K. Kosanke, 'Taming Triangle Diagrams', Pyrotechnica VIII, 1982
19. United Nations, Manual of Tests and Criteria, 2019, https://unece.org/sites/default/files/2023-08/ST-SG-AC10-11-Rev7e_final_0.pdf

APPENDIX

Construction of sawing aid / paper box template

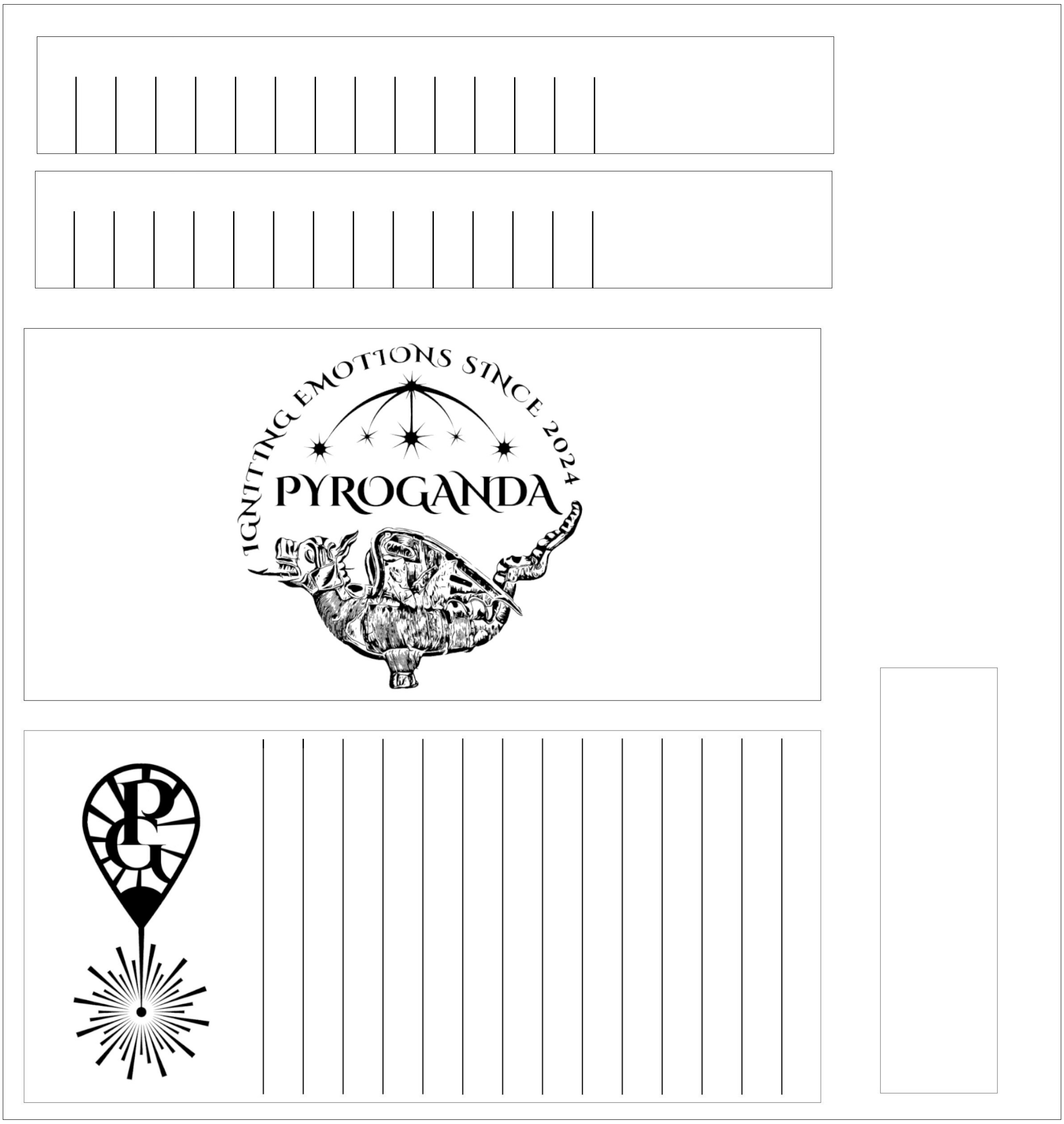

Figure 37: Laser-cutting template for the construction of the sawing aid. The width of the frame surrounding the components should be set to 200 mm. The template is designed for a 5 mm thick sheet of material.

Figure 38: The cut-out components.

Figure 39: The components are assembled, after which thin foam mats are glued to the interior and the loose panel.

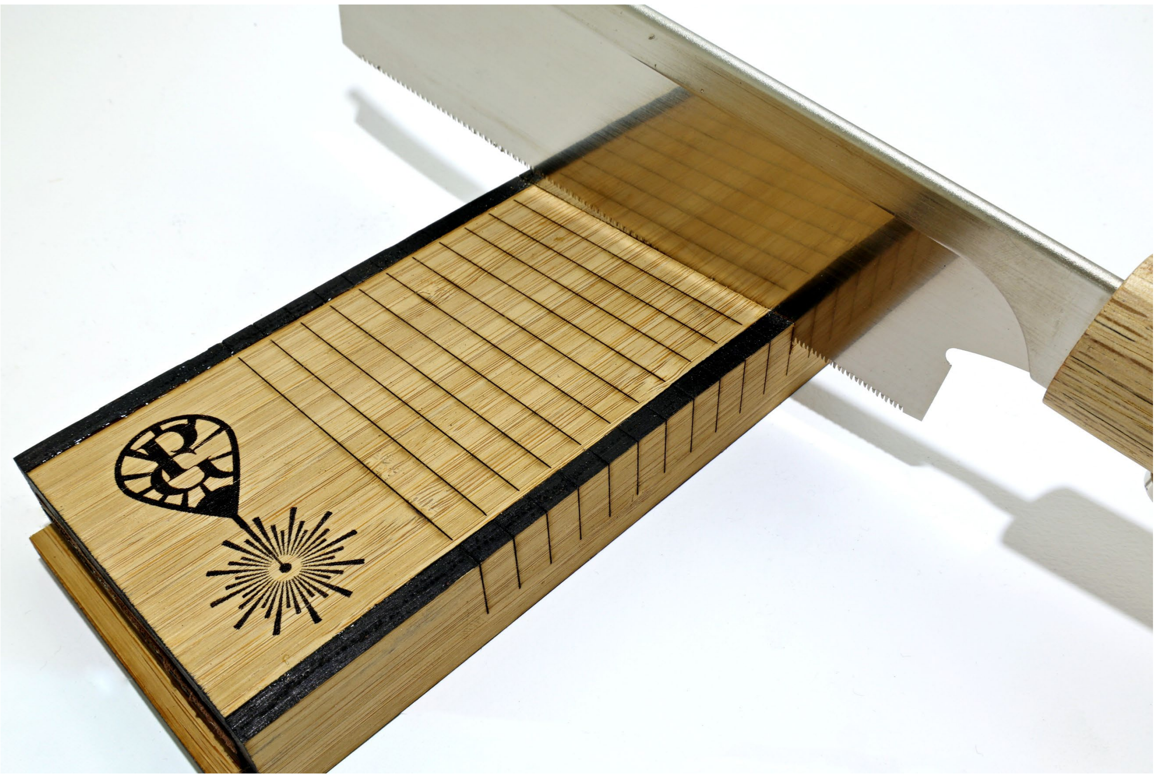

Figure 40: The ends of the spacers are now cut loose with the pull saw. It is important to fully coat the glue sides of the components with adhesive so that the individual spacers remain securely attached to the supporting sides during this phase.

Figure 41: In this image, on the left, you can see the cover plate made from two cut-out elements that were glued slightly offset against each other. This results in one plate slightly protruding from the saw guide, making it easier to open (see also figure 40 on the left). Alternatively, one plate can be made slightly larger. In any case, two plates need to be glued together to achieve the necessary thickness for applying pressure to the sticks. In the center, the matching sieve is visible, made from slightly longer sides onto which a non-stick grill grate has been glued. On the right, you can see the glued foam rubber layer that has been sawed through together with the bamboo sheet.

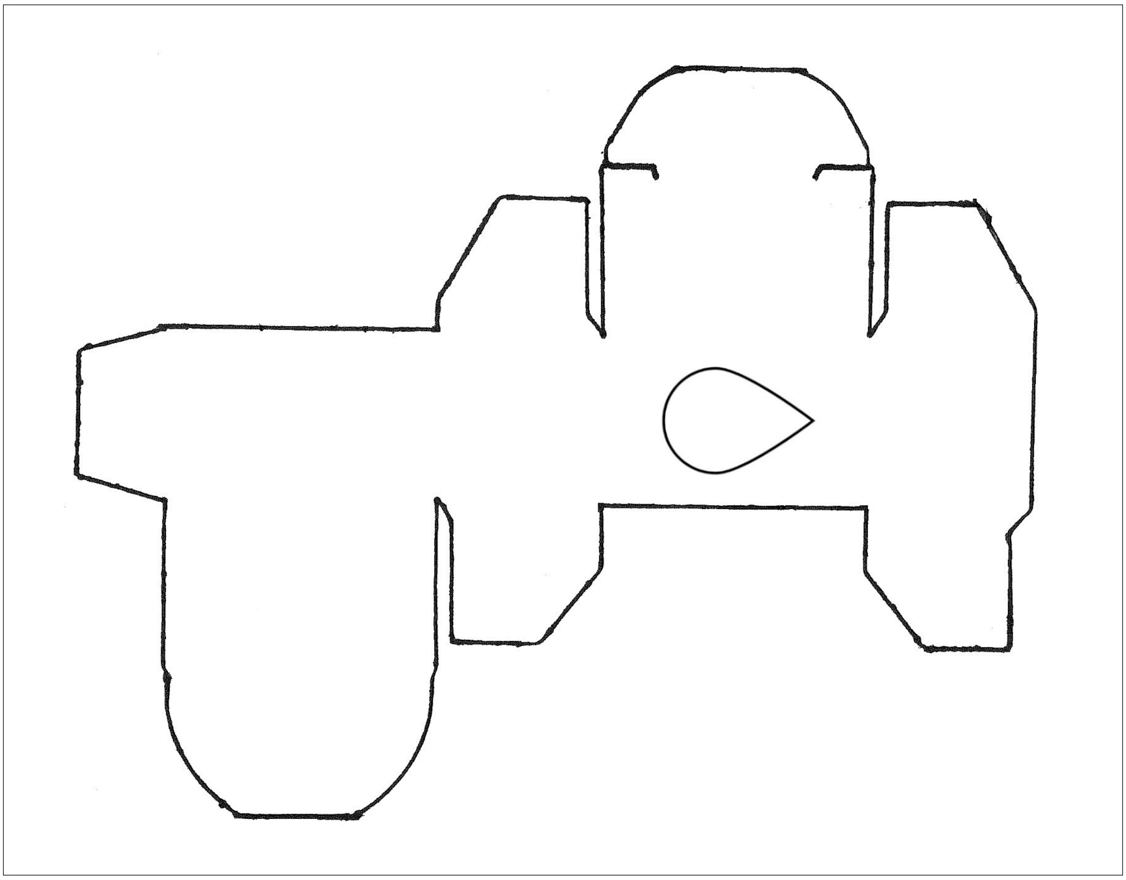

Figure 42: Template for the paper boxes in figure 36. The width of the frame should be set to 150mm. In this way, this template creates a custom box for a cut piece of paper roll that is 30mm wide.