The Senko Hanabi Sparkler:
A Study Of Factors Affecting Construction And Performance

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Abstract: *This article describes the many variables that influence the proper functioning of a senko hanabi sparkler. Standardization of these variables led to the development of a reliable and optimized device. On top of this, two new effects were added to the traditional design, the first being a diversification and maximization of the spark effects by splitting the composition. The second innovation is the addition of pure magnesium that gives the sparkler a spectacular glitter finish. The possibility of producing a significantly colored glitter other than white and yellow, is brought into question by the current experiments.*

Keywords: *Senko hanabi, sparkler, satori effect, glitter*

Preface

This article is the first to emerge from a comprehensive study of the senko hanabi sparkler. The findings of this study are of a practical as well as of a theoretical nature. This first part will deal with all of the practical insights that influence the performance and construction of a senko hanabi sparkler. Also, it will provide the reader with some historical and pyrotechnic background. The second part of the original study will be published as an accompanying article that focuses on the reaction mechanisms that take place inside a senko hanabi droplet.[1] The relevant literature will be reviewed and compared to some new experimental findings.

I hope this first article will be a starting point for other pyrotechnicians to construct this fascinating yet surprisingly challenging pyrotechnic device that combines a high level of safety with enchanting beauty.

Introduction

What is senko hanabi?

Senko hanabi is a traditional Japanese sparkler. It displays one of the most beautiful and intriguing pyrotechnic phenomena: a mesmerizing spectacle of delicate sparks that explode into pompoms of fire. This magnificent display is shot from just one boiling drop of pyrotechnic melt, suspended from a paper string (Figure 1).

Senko Hanabi sparklers originated in Japan in the Edo period (1603–1868). In the pleasure quarters of Osaka, they were burned next to incense sticks that kept track of time while men enjoyed the Geisha delights. After WWII, they were very popular until their labor intensive production shifted to China around 1980. Then, in 2000, several Japanese fireworkers started producing them again. Despite the fact that they are still more expensive than the Chinese ones, the Japanese senko hanabi sparklers are preferred because of their performance and elegant finish. In Japan they typically come last at families' firework parties and because of their relative safety, they can also be enjoyed by children (Figure 2). The sparklers evoke an emotion that the Japanese call "mono no aware", the feeling one gets when confronted with the beauty and transience of life.[2]

What's so special about senko hanabi?

Until now, the senko hanabi sparkler has remained relatively unknown outside of Japan. Yet it has some attractive features for the spectator as well as for the pyrotechnician.

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Figure 1. *A collection of split-composition senko hanabi 'Satori' sparklers. The 'Golden series' sparklers on the right contain some sodium bicarbonate to generate a golden-yellow glitter finish. The nine depicted sparklers together weigh less than 1.5 gram.†*

Figure 2. *Children's fireworks – senko hanabi, Miyagawa Shuntei, 1896.*

- Because its performance is influenced by many variables, every single sparkler goes through its own unique life-cycle. This makes every new sparkler potentially the most beautiful one has ever seen. This is opposed to the more uniform and predictable dipped sparklers.
- The different types of sparks can be enjoyed from up close and probably are the most refined in the whole world of pyrotechnics (Figure 3).
- Because of its small size, a senko hanabi sparkler is very safe during production as well as burning. One sparkler contains the same amount of pyrotechnic composition as 5 matches. On top of this, the ingredients are relatively insensitive and non-toxic.
- When compared to other types of firework, a senko hanabi sparkler has a very favorable production-time/effect ratio. It also provides the pyrotechnician with direct insight into the nature of glitter phenomena.
- The possibilities for experimenting with the formulation, the many possible additions and

Figure 3. *Typical display of soot-sparks.*

Figure 4. *Satori-phase, a medusa of other-worldly sparks.*

different methods of production are endless. On top of that, multiple sparklers can be combined to give miniature firework shows.

Why this article?

Although the senko hanabi sparkler has already been enjoyed for many centuries, many variables that affect the performance have even never been described in the literature. Therefore today it is a surprisingly difficult challenge to produce a reliable senko hanabi sparkler, even for an experienced pyrotechnician.

The research behind this article was primarily aimed at defining the many different variables that affect a senko hanabi sparkler's performance and to

Figure 5. *A finished 2-stage senko-hanabi sparkler.*

determine their relative importance. This resulted in a standardised procedure for the production of an efficient and reliable device. Additionally, two newly discovered elements that diversify and enrich the sparkler's traditional design are discussed. These elements are the introduction of a rebirth-phase ('umarekawari' effect) and secondly the incorporation of a pure magnesium glitter ('satori' effect, Figure 4). Also, some attempts to produce colored glitter are discussed.

Construction of a senko hanabi sparkler

What follows is the step-by-step procedure for making a reliable and efficient senko hanabi sparkler (Figure 5). The design was optimized so that the sparkler will function in zero-wind conditions as well as in light winds. Moreover, two new techniques are added to the traditional design. Splitting the composition by carbon-type makes the sparks bigger and more diverse. This

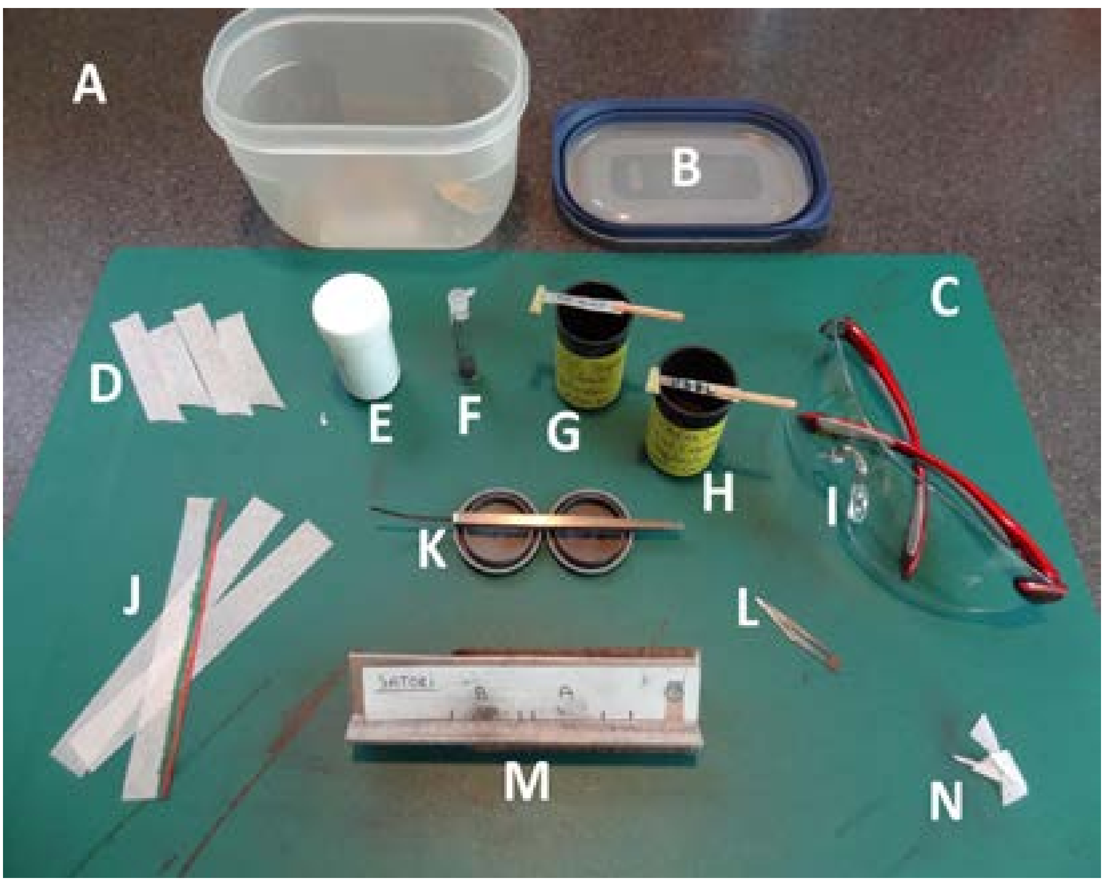

Figure 6. *Overview of working area.*

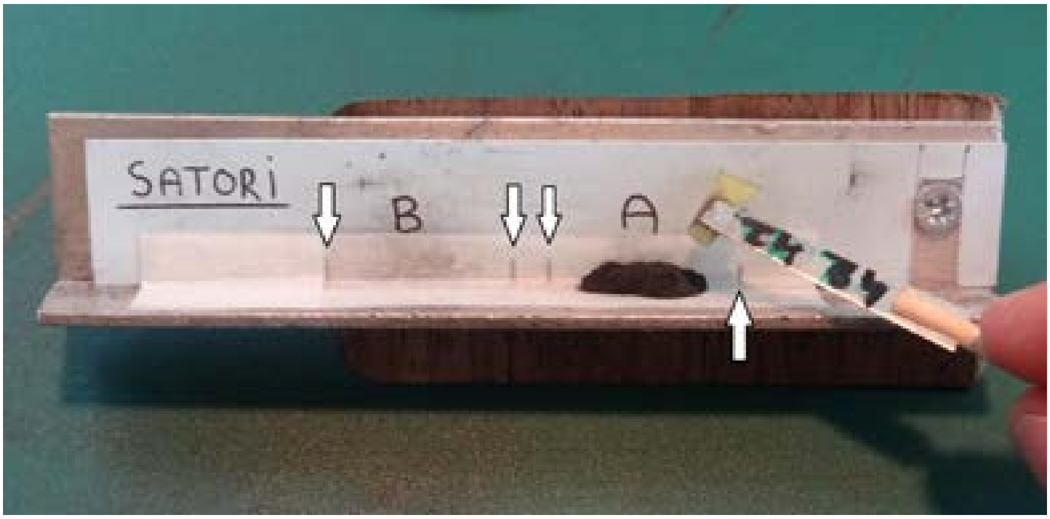

Figure 7. *Close-up of markings and spoon.*

also allows for the addition of pure magnesium to the composition. This second innovation adds a spectacular finish to the end of a senko hanabi sparkler's performance. The sparkler was named after this crackling metal-glitter effect: 'Satori', a zen term that means 'sudden enlightenment'.

Because the ingredients and materials will vary according to local availability, the design will likely have to be fine-tuned. Consulting the methods and results from this study will help in doing these final adjustments.

Overview of the working area and materials (Figure 6)

A: fire-proof working surface

B: hermetically sealing box with lid that easily pops off in case of overpressure

C: cutting mat

D: plain tissue-paper for finishing the sparkler

E: salt used for special effects (e.g. $NaHCO_3$ for yellow satori flashes)

F: magnesium powder treated with linseed oil

G: soot composition with specific spoon

H: charcoal composition with specific spoon

I: polycarbonate safety-glasses

J: Gampi-paper strips

K: small flat spatula with rounded end

L: sharp knife

M: aluminium paper holder on wooden base

N: cut ends of paper

Construction procedure

A strip of Gampi-shi Silk Tissue paper (Awagami-factory, Japan), 16 mm wide and 12 cm long is put on the aluminium holder on a fixed point. At the other side, the strip is folded back upon itself until it reaches the last marking (Figure 7, left arrow). Then, the strip is folded lengthwise in the middle and put back in the holder.

The compositions to be used are prepared in a mini-ball mill in which 20 g of combined ingredients and 40 ml of hexane are mixed for 2 hours. After separating the resulting slurry from the lead balls, it is left to dry and forced through a 100 mesh screen (see also methods and results).

A dedicated spoon that holds a standardised amount of composition A (KNO_3 50/S 35/pine-charcoal 15) is loaded in 3 times and in between the spoon is tapped on the holder so that the composition settles and air-pockets are avoided. The surface of the spoon is leveled with the small spatula and all of the composition, about 42 mg, is poured out on the paper strip in zone A. The same procedure is applied to composition B so that 42 mg are placed in zone B. After this, one uses the rounded tip of the spatula to distribute both compositions evenly between the markings. The spacing between both

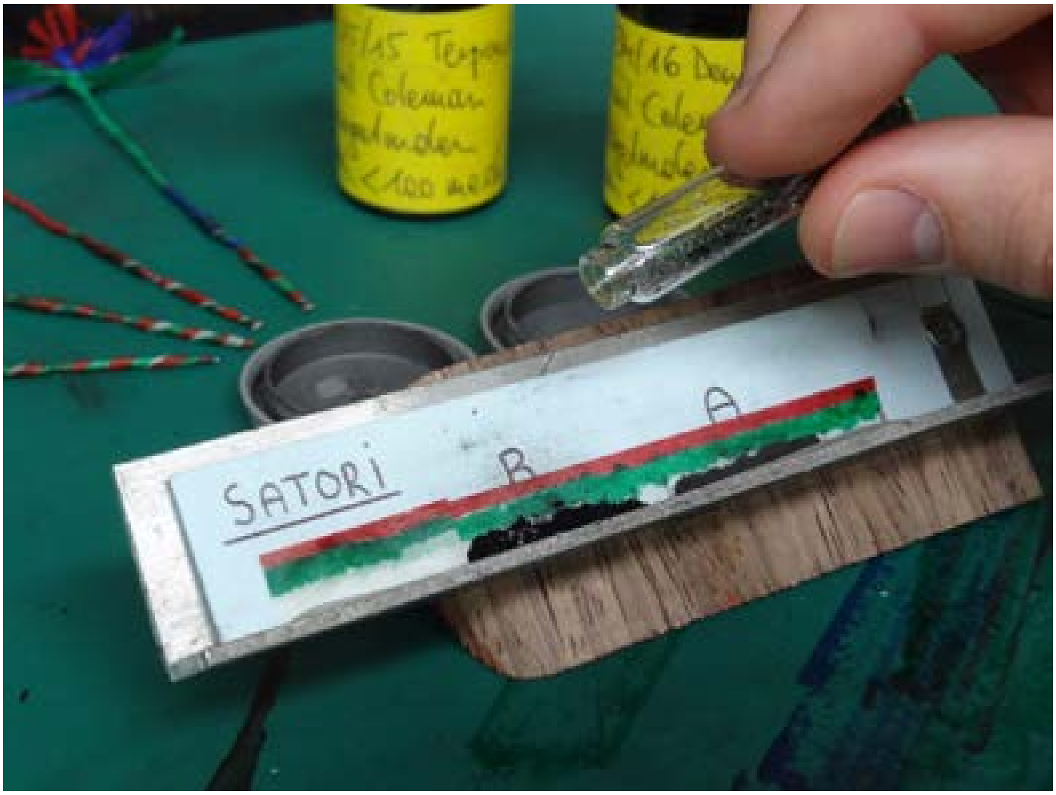

Figure 8. *Compositions in place.*

compositions is about 4 mm. The holder is raised and gently knocked on the working surface so that both compositions can settle out. Finally, a few grains of magnesium are seeded over the last 1 cm of composition B (Figure 8). Optionally, a few mg of a salt can be added to provide an extra effect, e.g. $NaHCO_3$ to color the satori flash yellow.

Now one takes the paper strip from the holder and starts rolling it onto a sparkler. Right-handed people take the folded strip between thumb and index finger of their left hand, while the right thumb and index finger start twisting the end of the strip into a string. The left hand exerts very little pressure while doing this. The angle between the strip and the string is about 45° while rolling the first composition, but when one arrives at the space between compositions, the right hand further increases this angle until it reaches 60–80° (Figure 9).

When rolling the second composition it is even more important not to use too much pressure so that the string isn't twisted too tight. Near the end of the second composition, the angle of rolling is now lowered again to 45° and this angle is maintained for the rest of the sparkler. At this moment, one is left with approximately 1 cm of folded strip. This is cut open with a sharp knife and between the two layers, one inserts a strip of plain tissue paper whose beginning was cut to a 45° angle beforehand (Figure 10).

Now the strip is further rolled into a string and the sparkler is finished by folding back the end of the strip so that the final portion of the string is thicker and the ascending melt-droplet is stopped, protecting the fingers. If price and availability of Gampi-paper is of no concern, then the sparkler's construction can be simplified by starting with a much longer strip of Gampi-paper and to also use it beyond the critical reaction zone.

After rolling, the sparkler should be compressed/tightened over its full length by twisting it firmly between thumb and index fingers of both hands. Only the middle of the second composition should not be compressed to retain its reactivity.

Finally, one cuts the sparkler at the start of the first composition, so that it can be easily lit.

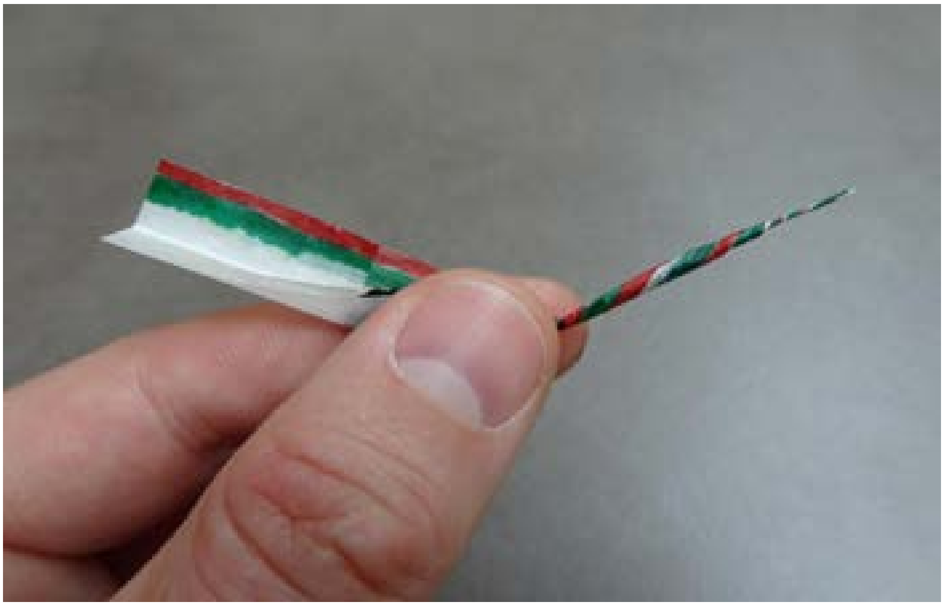

Figure 9. *Twisting the paper strip. Note that the colored lines now create a 2-color spiral.*

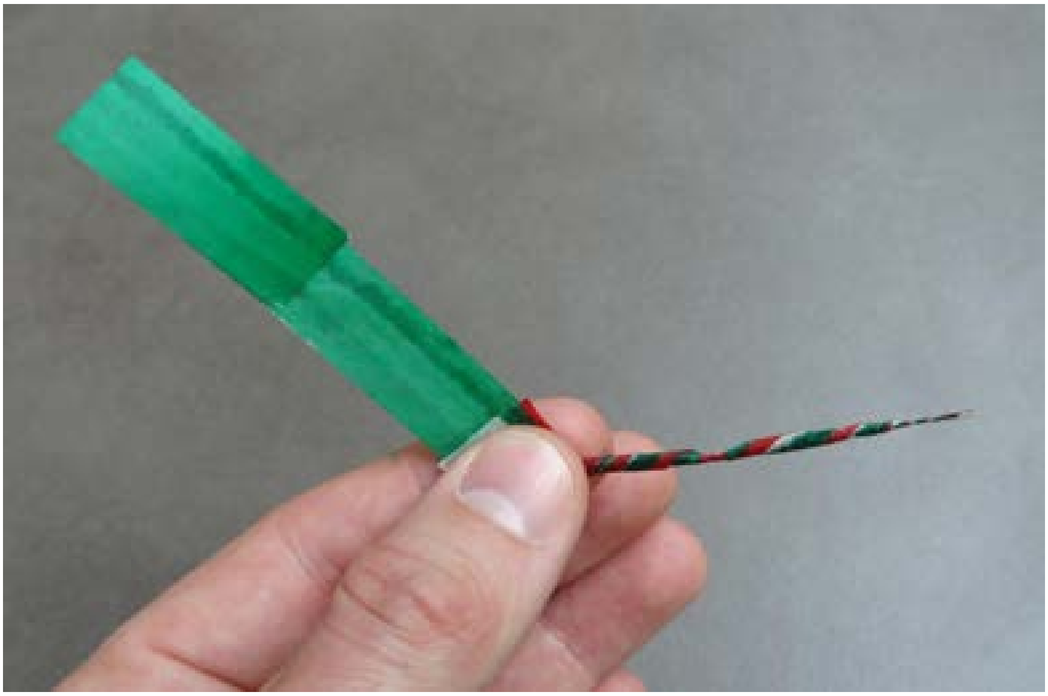

Figure 10. *Adding plain tissue paper.*

Lighting the sparkler

The beauty of the delicate senko hanabi sparks is easily washed away by ambient light. If possible, light the sparkler in absolute darkness. It is amazing how much this adds to the effect.

The boiling of the dross ball and the firing of the charcoal and soot sparks also produce enjoyable sounds that are best appreciated in a quiet environment.

Last but not least, a senko hanabi sparkler is very sensitive to wind. Too much wind simply blows off the droplet. However, in still air there is frequently no satori effect. The full range of effects must therefore be enjoyed in minimal wind conditions, which are in fact more common than zero-wind conditions.

Senko hanabi sparklers should always be lit outside above a fireproof surface. The dross ball can (and will) fall off and is capable of staying hot for a very long time by the very nature of the senko hanabi phenomenon. Occasionally, a falling droplet mildly explodes when it hits the ground.

An alternative way to appreciate a sparkler is to wait for the moment where the sparks start to emerge and then shoot the drop away with a finger. This gives rise to a surprising display of sparkling drops that fill the air in front. Of course, one should always aim towards a fireproof area and well away from other persons (Figure 11).

Troubleshooting

The dross ball doesn't form

- Wrong formulation: try adding more sulphur. Soot-based compositions are less reactive than charcoal-based ones.
- Too much paper: try using thinner paper or using a narrower paper strip.
- High heat dissipation: try rolling the sparkler more perpendicular to the strip so that it gets shorter and more compact.
- Too much salt added.

Figure 11. *Just one drop of polysulfide melt shot with a fingertip.*

The dross ball drops

- Too much composition: gradually lower the amount.
- Too much wind.
- Jet of reaction gases blows off the droplet: try rolling the sparkler more perpendicular to the strip so that the jet is aimed outwards instead of downwards.
- Viscosity too low: lower the amount of soot.
- Paper string above dross ball is burned: use a double layer of paper just behind the composition. Try unwinding the region just behind the composition a little bit.

Sparks are small

- Suboptimal formulation: systematically test compositions around the current one by means of the composition triangle (see methods and results).
- Wrong type of carbon: use soot for larger sparks.
- Dross ball continues to climb, thereby consuming paper and lowering its overall reaction rate and temperature: add more twist to the paper just behind the composition. A tightly wound paper string slows the ascent of the drop.
- Too much wind: wind stimulates the formation of many but shorter sparks.
- Addition of salts: only use the minimal amount necessary.

Dross ball is blown off when arriving at the second composition

- Second composition reacts too fiercely: while rolling, put some more pressure on the starting zone of the second composition so that air pockets are minimized.
- Jet of gases blows off droplet; increase the angle of rolling so that the jet is aimed outwards.

No satori effect

- Magnesium was burnt in the initial phase: only add magnesium to soot-based compositions.
- Not enough magnesium: try adding just a little bit more.
- Still air: light the sparkler outside in very light wind conditions or gently blow on the reacting drop.

Satori effect comes too soon

- Too much magnesium, add less.
- Addition of $NaHCO_3$: lower the amount of this salt.

No old-age phase‡

- Suboptimal formulation: test others.
- Gently unwind the paper string behind the last composition.

Methods and results

For each variable the method used and the observed results are grouped together. As a general methodology it can be stated that when one variable is adjusted, the others are kept as constant as possible. Most of the experiments were video-recorded for better analysis later on.

The paper factor

Paper type

Method: Tissue paper, wrapping paper for shoes, different brands of commonly available tissue paper and a few types of handmade Japanese paper were tested.

Results: Thickness and tear resistance are the main points of interest. Because the polysulfide reactions require atmospheric oxygen, neither the paper nor the residual ash may shield the melt from air. If the paper is too thick, the gases that are evolved may blow off the dangling droplet by creating a tube. On the other hand, the fibres present in the paper keep the drop attached. Standard tissue paper (e.g. ‘Canson’) works, but is still quite thick (20 g m^{-2}) and tears easily when twisted. ‘Gampi-shi Silk Tissue (Awagami-factory, Japan)’ is both extremely light (10 g m^{-2}) and surprisingly strong. The fibres come from a bush that has been used by Japanese paper-makers since the 8th century. To date, no other type of paper has been found to be superior for the production of senko hanabi sparklers.

Width and fibre direction of the paper strip

Method: Paper strips were cut along their length respectively perpendicular to the direction of the fibres. The width of the strips was varied from 12 mm to 30 mm.

Results: Strips that are narrower than 14 mm are difficult to roll and can give leakage of composition. On the other hand, narrow strips seem to promote the start of the secondary polysulfide reactions. This might be explained by the lesser amount of paper that shields the reaction products from the air and by the smaller total amount of ash. On the other hand, broad strips can provide more suspension for the droplet. The thicker the paper, the more important its width. Looking at standard tissue paper, a clear difference in reactivity can be observed between strips of 14 mm and 16 mm. The Gampi-paper is more tolerant, and Ito as well as Saito use strips with widths up to 25 mm.[3,4] After experimental research, the aforementioned factors were found to be well reconciled by choosing a Gampi-paper strip of 16 mm. The direction of the fibres is important because strips that were cut perpendicular to the direction were very prone to tearing while being twisted.

Length of the paper strip

The traditional Japanese sparklers have a length of about 20 cm when finished. In making a sparkler, one can choose to use a very long strip of Gampi-paper or to use a strip of cheaper tissue paper after the critical reaction zone. Audiences seem to appreciate shorter strands of paper, different from the traditional Japanese design, so that the sparks seem to come out of their hands. This design also illustrates the innocent nature of the sparks when they touch the skin. In addition, they are easier to transport this way.

Coloring the paper

Standard tissue paper is available in many colors and this adds to the beauty of the sparkler. Black can be used for its invisibility in darkness, but this makes working with the black compositions harder. Another way of adding color is to color the paper oneself. This opens up many artistic possibilities such as spiralling colors by drawing colored lines lengthwise on the paper. One can choose to use natural dyes (Kimiko Saito uses safflower for pink, kihada for yellow, burdock for purple and a mixture of kihada and Japanese pampas grass for green[4]) or synthetic dyes like alcohol markers. An alternative is to color the sparkler once it has been twisted.

The composition: raw materials

Charcoal types

Method: Shimizu and others make use of both Paulownia-charcoal and pine-charcoal. For these experiments, they were prepared by putting twigs (4 cm diameter) of a young Paulownia-tree and stem-wood from *Pinus sylvestris* in a tin drum sitting on a bed of glowing barbecue charcoal. After cooling down, the charcoal within the tin drum was mechanically ground so that it passed a 100 mesh screen.

Results: Contrary to the findings of Shimizu, the sparks generated by the paulownia-charcoal were smaller and showed less branching than those from the pine-charcoal. The latter shoot approximately 10 cm away from the droplet in the first youth before they explode themselves into dense bushes of sparks a few centimetres in length.

Soot types

Method: Oglesby states that "Lampblack should be made at low temperature and quickly quenched. It consists of bulbous groups of imperfect rings and straggling twisted shreds of crooked chains with many branches coiling back on themselves and each other".[5] Traditionally, soot for senko hanabi sparklers is produced by burning the wood and resin of certain *Pinus* species (e.g. *Pinus densiflora*). In his S*tudies on Senko Hanabi*, Shimizu used soot made from burning anthracene.[6] Saito on the other hand uses soot made from the combustion of the roots of *Pinus* species.[4] The current experiments used pine-soot made by burning just the resin from European *Pinus* species and collecting it on the inside of a metal container. In the article by Ito, soot from burning turpentine was used.[3] This method was tested as well.

Results: The burning of turpentine proved to be the easiest way of producing soot and the quality of the soot did not seem inferior to that of pine resin. In the 'second youth', the sparks produced by these types of soot travelled an average of 20 cm away from the droplet. Sometimes the sparks reached more than 40 cm. In their 'middle age', these sparks still reached 10 cm. After their travel, they exploded into pompoms with sizes ranging from a plum to an orange.

Sulphur source

Only technically pure sulphur that passed a 100 mesh sieve was used for the experiments. Shimizu also describes finished items containing realgar (arsenic sulfide) as sulfur source for the polysulfide reaction.[8] The highly toxic nature and carcinogenic properties of this material and its reaction products make it unsuitable for use in a hand-held sparkler. Similarly, antimony sulfide, which is commonly used in glitter compositions, poses an unacceptable health risk both in the production and firing of these sparklers.

Potassium nitrate

Technically pure potassium nitrate was used that prior to the processing was sieved to <100 mesh.

Metal powders

For the experiments, pure magnesium powder (100 mesh), magnalium powder 50 : 50 (200 mesh) and atomized aluminium powder (0–325 μm) was used. The magnesium powder was protected from unwanted reactions by treating it with linseed oil in the following manner: 1 ml of boiled linseed oil was added to 25 g of magnesium powder and a sufficient quantity of hexane was added to moisten the powder evenly. Then the powder was allowed to dry for several days.

The composition: formulations

Methods: Many formulations were tested. Building on the research done by Shimizu, a starting ratio of 60 KNO_3/25 S/15 carbon source was used. Throughout the experiments this ratio was systematically changed by placing six points around this point on the composition triangle. The best performing composition (one that easily starts the polysulfide–air reaction and that generates big sparks) was selected and again six points were selected around this composition to further specify the optimal ratio of raw materials. Because the split composition design offers important advantages, few experiments were done to test mixed carbon-source compositions. Shimizu already studied the optimal ratio between charcoal and soot. It turned out to be 4 : 1. This specific ratio was also tested in a composition consisting of 50 KNO_3/35 S/12 charcoal/ 3 turpentine-soot.

Results: The experiments showed that the optimal ratio depends on the desired effect and on the other production variables. Of these, the most important one is the mixing method used. The formulations used by Ito (55/25/15/5)[3,7] and Shimizu (60/25/12/3)[6] are adapted to the mortar and pestle method. When more intimate mixing methods are used (see below), these formulations become too reactive and therefore not usable. After systematic screening of the composition triangle, the optimal ratio when processed by mini-ball mill slurry mixing seems to be 50/35/15, regardless of the carbon source used. Depending upon the direction in the composition triangle that the formulation travels from the reference ratio, specific changes in properties are observed. For example, a soot composition 54/31/15 is less efficient in its youth phase, but gives off more sparks in the old age. A soot composition 54/36/10 is very eager to start the polysulfide–air reaction, but does not give off sparks and gets stuck in phase 2. The description of the properties of all the different compositions tested would take an article by itself. A study of these properties could show trends depending upon the direction the formulation takes in the composition triangle.

The observations made by Shimizu concerning mixed carbon source compositions[6] were confirmed. Sparks travelled about 12 cm from the droplet. The flying range and size of the secondary explosions are however inferior to those generated by split compositions.

Mixing method

Method: A finished sparkler contains less than 90 mg of composition. Taking into account these small quantities used, even small deviations from total homogeneity of the composition can lead to noticeable differences in effect. It is therefore surprising to find that even in recent literature the mortar and pestle method is used.[3,6,7] This manual method however, is very difficult to standardize. Also, the degree of mixing remains inferior compared to automated techniques. For the current experiments, the raw materials were passed through a 100 mesh screen and different mixing methods were successively tested: mortar and pestle (intimate mixing for about 15 minutes), repetitive screening (20 times through a 60 mesh screen), 2 hours of dry ball milling in a mini ball mill (recipient of 100 ml and lead balls of 5 mm) and slurry ball milling in the same mini ball mill for the same time. The slurry was created by adding 40 ml of hexane to 20 g of composition in the ball mill. It is an adaptation of the Dupont black powder manufacturing technique.[9] After processing, the composition was again passed through a 100 mesh screen.

Results: All dry methods except screening led to caking of the composition. Only the slurry method provided a composition that showed no sparkler-to-sparkler variability. Hence this became the preferred processing technique.

Amount of composition

Method: The use of different amounts of composition was tested. These quantities were originally estimated by the naked eye but were soon weighed on a milligram scale for reasons of standardization. Eventually a measuring spoon was developed that was able to contain reproducible amounts of composition. The properties of this milligram spoon are that it has a smooth surface and very thin surface, so that no powder can stick or rest on it. The arm of the spoon also has to be smooth and very thin for the same reasons. In addition, a rounded end makes it easier to turn the spoon during filling and emptying. Such a spoon was constructed by welding a drinking straw together, gluing a strip of a tin can to it and inserting this into a split bamboo skewer. Many scoops were made this way and each was filled 20 times with composition and the amounts were weighed on a milligram scale. They proved to be reliable and thus the use of the milligram scale became superfluous.

Results: The optimal amount of composition is a trade off between the size of the effect on the one hand and the falling of the polysulfide drop on the other hand. Depending upon the other variables, this amount is between 80 and 90 mg, in accordance with traditional and current literature. In the case of a split composition sparkler, the maximum total amount remains the same.

Addition of metals

Method: Magnesium powder, magnalium powder and aluminium powder (for specifications see 'raw materials') were added to charcoal compositions, soot compositions, mixed compositions and to the soot portion of split compositions. The amount added varied between 1 and 10 mg.

Results: Magnesium can only be added to a soot-based composition. If charcoal is present, the reaction temperature is higher and the magnesium is burnt in the first phase. Magnalium and aluminium are less reactive[10] and can also be added to charcoal-containing compositions. The experiments also showed that only magnesium powder is reactive enough to produce the satori effect in the wind conditions a senko hanabi sparkler can be fired in. So the high reactivity of magnesium is in fact a necessity for it to be used in senko hanabi sparklers. In still air, there frequently is no satori effect. However, the slightest breeze can reliably trigger the effect. Concerning the amount of magnesium to be added, it seems that just a few grains are enough to provide a spectacular finish to the sparkler. Adding more magnesium decreases the time to the satori phase and makes the drop react completely in one flash, like traditional glitter.

Other additions:

The effect of adding different salts to classic glitter compositions has been studied extensively.[11] Now, some of these substances were put to the test in senko hanabi formulations. However, toxic and/or corrosive substances were left out: arsenic sulfide, antimony sulfide, calcium oxalate, sodium oxalate, lithium oxalate and barium nitrate. Only sodium bicarbonate and strontium oxalate have an acceptable health risk for a hand-held device.

$NaHCO_3$:

A small amount (2–5 mg) of sodium bicarbonate was added to the soot composition containing magnesium. This caused significant changes in the melt chemistry and spark effects. Instead of the usual sparks, small droplets were emitted which create a kind of 'rain effect'. Also, the addition of $NaHCO_3$ made the magnesium react earlier. The typical corkscrew sparks were absent and the flash reaction was observed to come only from the surface of the droplet. The flashes clearly emitted a deep yellow color (Figures 12, 13).

Li_2CO_3, $Li_2C_2O_4$, $SrCO_3$ and SrC_2O_4

Method: A few milligrams of lithium carbonate, strontium carbonate, lithium oxalate and strontium

Figure 12. *Indirect light from satori flashes with added salts.*

oxalate were added to the soot composition of split composition sparklers containing magnesium.

Results: The carbonates had a strong inhibiting effect on the reactivity of the polysulfide melt. In a senko hanabi sparkler, they don't seem useful. The oxalates have less of an inhibiting effect, and make the polysulfide melt emit sparks similar to those of $NaHCO_3$. Live sparklers, pictures and stills of video-recordings showed no significant coloration of the flash in comparison to pure magnesium (Figures 12, 13: the indirect photographs show a pinkish hue with strontium oxalate, but to the naked eye the flash remains white).

$Sr(NO_3)_2$

Method: In analogy to Winokur's glitter composition #1, an equal portion of the potassium nitrate was substituted by strontium nitrate. This led to the formula 35 KNO_3/15 $Sr(NO_3)_2$/35 S/15 turpentine soot. The composition was processed like the others i.e. 2 hours of ball milling with added hexane. This composition was used alone and as a second phase in a split composition sparkler.

Results: The presence of $Sr(NO_3)_2$ clearly changed the melt chemistry and led to the emission of many drops which gave the reaction a pronounced 'rain effect'. The magnesium flashes did not change character like with $NaHCO_3$, and there was no significant color change comparing to pure magnesium flashes.

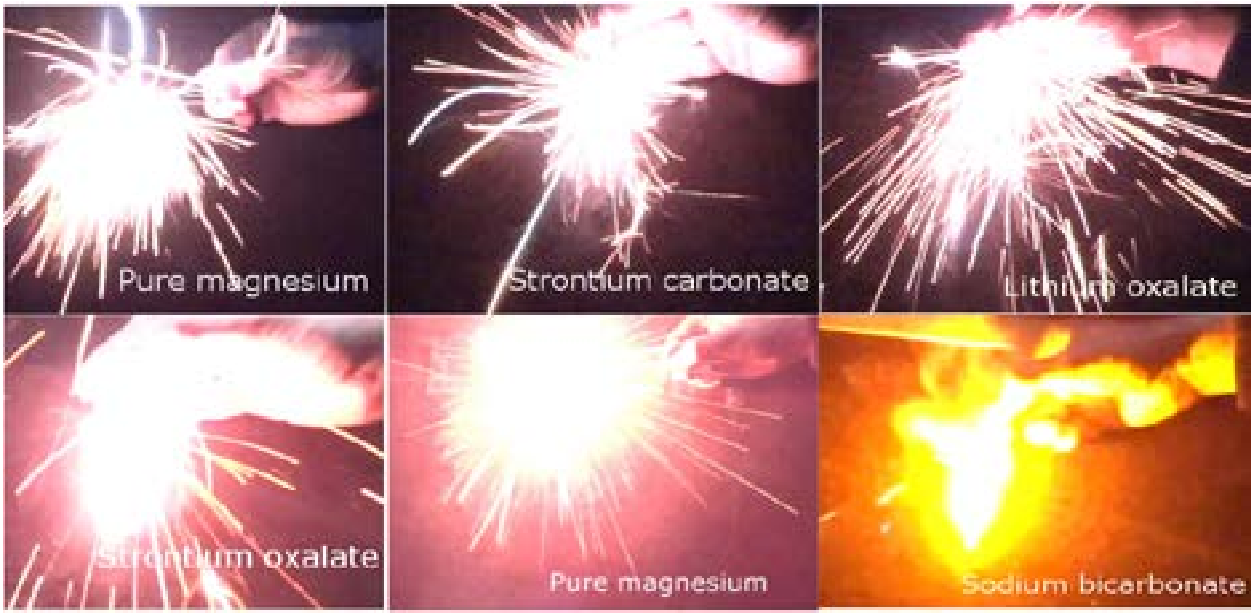

Figure 13. *Satori flashes with added salts.*

Production method

Placement of the composition on the paper strip

Method: the composition is put in the middle of the paper strip over a distance that ranges from 2–4 cm. Both single composition and split composition sparklers were thus tested.

Results: the optimal length of composition on the paper also depends upon the way the strip is wound up. In general, the composition is best placed over a length of 2.5–3.5 cm. Spreading the composition over shorter distances leads to faster and more violent burning which makes the reaction products less likely to form a reactive melt. In split composition sparklers however, the second one can be spread over a shorter distance, because the first one has already started the polysulfide–air reaction. This makes it easier for the reaction products of the second composition to start reacting themselves. In addition, because the second composition is frequently soot-based, the faster and hotter consumption can be an advantage.

Multiple compositions and spacing

Method: Two or more quantities of composition are put in sequence upon the paper strip. Experiments were done with sequential charcoal compositions, sequential soot compositions and soot compositions following a charcoal composition. The gap between these compositions was varied from 2 to 20 mm.

Results: Charcoal compositions reliably pass on to the middle-age and old-age stages. This way, the paper gets consumed while the polysulfide drop climbs up on the string and can ignite a following composition. It was found that using a 50/35/15 pine-charcoal composition, it is possible to create a string of consecutive reaction zones. Polysulfide drops from soot-based compositions on the other hand have a tendency to remain stationary and die out. Therefore it is better to let a soot-based composition follow a charcoal-based one. Moreover, this way the sparks get larger in consecutive phases.

The spacing between compositions determines when the reacting polysulfide drop makes contact with the next composition. If one increases this length, the drop will have had more time to show its typical display of sparks. On the other hand, when the distance between compositions is kept short, the second composition is consumed while the first is fiercely reacting. This in turn promotes the reaction of the second polysulfide drop. Especially for soot-based compositions, this stimulation is beneficial. So the spacing is a trade-off between viewing the spark display of the first composition and the reactivity of the second. It was found that the optimal spacing distance is 2–6 mm, depending upon the angle the paper makes while rolling the sparkler.

Folding back the strip

Method: Before folding the strip lengthwise, it is folded back over itself so that the final portion is double-layered. The length of this overlap is varied.

Results: The greater the overlap, the more the reactivity of the second composition is tempered to the point where it is not capable anymore of starting the polysulfide–air reaction. If the overlap is made shorter however, the polysulfide drop is less suspended and therefore more prone to falling. In the current experiments, an optimum was reached by folding the strip back to the end of the second composition, or a few millimetres further towards the beginning.

Angle of rolling

The angle at which the paper strip is rolled was varied from almost parallel to the length of the paper to perpendicular to it.

Results: Depending upon this angle, the composition shows differences in burning rate (the more perpendicular, the faster it burns), the direction of the flow of the combustion gases (the more perpendicular, the more the flow is directed sideways), the reactivity of the polysulfide melt (the more perpendicular, the faster the polysulfide reaction will take place) and adhesion of the drop to the paper string (the bigger the angle, the better the adhesion). The following procedure has shown to best take into account all of these elements. One starts with a paper strip folded lengthwise with two compositions spaced 5 mm apart. If one starts rolling at the firing end, the left hand holds the strip between thumb and index, while the same fingers from the right hand start twisting the paper at an angle of 45°. If one starts with a paper strip of 16–20 mm wide, one can observe in the finished sparkler two zones that spiral around each other. The darker zone is where the composition is covered by only one layer of paper, the lighter zone is where three layers of paper cover the composition. This way, the reaction products have a zone in which they can easily react with the atmospheric oxygen and another one that helps in suspending the drop. After rolling the first composition in a 45° angle, the angle is increased to 60–80° when arriving at the intermediate zone. This ensures that the paper string gets slightly thicker to prevent the reacting first drop to fall. The second composition is rolled up in the same angle. This way, the soot-based composition is consumed faster (promotes reactivity) and the reaction gases are directed sideways, preventing the drop from being blown off. Arriving at the end of the second composition, the angle is again lowered to 45°.

Compacting the composition and winding the paper string tight

Method: After rolling, the sparkler is twisted with extra force so that some regions are more compacted than others.

Results: The compaction of a certain region of the sparkler tempers the burn rate of the composition, probably because air pockets are squeezed out of it. The experiments show that charcoal-based compositions are best compacted. Soot-based compositions on the other hand seem to gain reactivity when they are kept somewhat loose. If the paper string just behind a composition is more firmly twisted, the tendency of the resulting polysulfide drop to climb up the string is lowered. The drop stays stationary, and this enhances the display of sparks because less non-reactive material is added to the melt. Further on the string, providing less twist can stimulate a prolonged 'old age' phase. So for best results in a typical split composition sparkler, one compacts the charcoal-based composition (to temper the very reactive composition), the string between first and second composition (to give the first polysulfide drop the opportunity to display its typical sparks), the first millimetres of the second composition (to prevent a fierce reaction that blows off the first droplet) and the string just behind the second composition (to let it display its characteristic sparks). Practically, the extent to which the paper can be extra tightened is largely determined by the type of paper used. The aforementioned Gampi-paper is much more tear-resistant than standard tissue paper.

Applying a coating

Applying a coating to a sparkler can make it more water-resistant and can keep it from unwinding during transport.

Method: After rolling, sparklers were immersed in different solutions: 10% celluloid (ping-pong ball) in acetone, 10% shellac in ethanol and collodion.

Results: Coating the sparkler with shellac leads to the composition reacting very slowly and the coating catching fire. Celluloid dissolved in acetone inhibits the reactions less but the coating still occasionally catches fire. The polysulfide reactions still start, although less vigorous. Collodion puts a thin cellulose nitrate coating around the sparkler. This treatment seems to influence the normal reactions least of all. In general however, coating a senko hanabi sparkler reduces its performance.

Firing conditions: wind speed

Method: Senko hanabi sparklers were burned in still air and in very light winds. The wind speed during the experiments was standardized using a small fan that was aimed at the sparkler.

Results: Wind speed proved to be a crucial factor affecting performance. More wind makes the sparkler react faster and more vigorously. The largest sparks however are observed during low to zero wind conditions. It was observed that the satori effect frequently failed to show in zero wind conditions. So a little wind gives optimum overall performance. The ideal wind speed lies therefore between the one that just causes the magnesium to react and the one at which the drop falls.

Conclusion

This article is probably the first to describe the many variables that influence the proper functioning of a senko hanabi sparkler. Standardization of these variables led to the development of a reliable and optimized device. On top of this, two new effects were added to the traditional design, the first being a diversification and maximization of the spark effects by splitting the composition. The second innovation is the addition of pure magnesium that gives the sparkler a spectacular glitter finish. The possibility of producing a significantly colored glitter other than white and yellow, is brought into question by the current experiments.

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Notes and references

† All figures are made by the author except for Figure 2, source: Japanese art open database.

‡ Traditionally, the different burning stages of a senko hanabi sparkler are seen as phases in the sparkler's life. In the described satori design, these stages are: 'birth': fuse like burning; 'infancy': formation of a dross ball; 'youth' and 'middle age': emission of charcoal sparks; 'rebirth' and 'second infancy': consumption of the second composition; 'second youth' and 'second middle age': emission of soot sparks; 'old age': silent emission of long streaky sparks; 'satori' crackling glitter flashes. For an in-depth description of these phases, see reference 1.

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