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Title: Characterisation and Fragmentation of Brass and Copper Pipe Bombs when Using Different Initiation Locations

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The fragmentation characteristics of pipe bombs made from copper and brass, filled with a single base propellant, and initiated with an electric match positioned either at the end or halfway along the pipe were studied. A rig was devised to negate any variation from the effectiveness of end caps. Fragments were captured in strawboard packs and recovered to enable imaging and Fragment Weight Distribution Mapping (FWDM) graphs. The position of the initiator had a measurable effect on the fragmentation of the copper pipe, with the middle-initiated pipes having a higher relative power. In contrast, no such clear link was evident for the brass pipes. This likely indicates that the initiator location has less of an effect in stronger materials which are able to confine the propellant prior to rupturing.

INTRODUCTION

One of the more commonly recognised types of improvised explosive device (IED) is the pipe bomb. The simple construction and hence ease with which the necessary materials can be obtained to build them, as well as the availability of unorthodox literature providing step by-step guides to assemble them, makes the pipe bomb a common type of IED [1]. However, despite their relatively simplistic construction, there is no fixed design for these devices as the components/materials that can be used are interchangeable. The individualisation of each pipe bomb influences its lethality and viability, meaning that each incident involving such a device is unique.

Post blast investigators will try to collect evidence that provides information such as who designed the device or the materials used, and where they bought them from [2]. Although various forms of evidence are investigated, one method of gathering information from a pipe bomb is by examining the resultant fragmentation of the device.

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Various features may be looked at, such as the fragment mass of recovered component pieces as an indicator of the device's relative power, or how the container wall-thickness is affected after initiation [3][4][5][6]. Hence, by researching these aspects through controlled experiments, investigators will be better equipped to identify the design and construction of real devices. Therefore, design and material factors that affect the fragmentation characteristics need to be understood if the interpretation of the evidence is to be accurate.

A pipe bomb generally consists of a container, end-caps, an initiation mechanism and an explosive charge [2]. The charge can vary from propellant, or a home made explosive to military grade explosives [2][7]. The container is typically cylindrical in shape and consists of, but is not limited to, a pipe made of metal or plastic [8]. For low explosives, the container/end caps confines the explosive to allow the pressure to build up as the filler is ignited, before the device bursts and fragments are propelled outwards at high speeds [9]. The effectiveness of the confinement inevitably contributes to the explosive power for a given low explosive. Premature rupturing of the pipe/detachment of the endcap can therefore prevent full detonation. Hence deconflicting the fragmentation of the container, against the effectiveness of the endcaps in sealing the pipe confounds the difficulty in understanding fragmentation.

There are various methods with which a pipe bomb can be initiated, but they can generally be classed within four mechanism systems: heat, electrical, mechanical and chemical. Initiation is necessary to provide enough energy to either deflagrate or detonate the main charge or energetic filler. Reviewing prior pipe bomb incidents, electrical initiation through an electric match or blasting cap was regularly implemented [7].

Fragmentation

When initiated, a pipe bomb is subjected to rapid pressure build-up from the gaseous expansion of the decomposing energetic filler, causing it to expand before fracturing into multiple fragments. Investigators will closely examine the fragments of the container to firstly identify this type of device, and they can be an indicator for the kind of explosive filler and initiation system used.

The explosive filler or main charge used in a pipe bomb is one of the determinable features of how the container will fragment. The velocity with which a pipe bomb deflagrates or detonates and the shock pressure it generates affects the how the container material fragments [2]. In addition, the initiation system used will also influence how the pipe bomb fragments. As highlighted by Beveridge, if the energetic filler has the energy to do so, it will take on the velocity of the initiation mechanism [2]. To the authors knowledge, no one has investigated the effect of the position of the initiator has on fragmentation.

The material properties of the container inevitably contribute to the fragmentation characteristics. Whilst dynamic behaviour is difficult to quantify, quasi-static strength, ductility and toughness will affect fragmentation. Much of the open-source research focuses on the fragmentation of steel and polyvinyl chloride, meaning there is a lack of information regarding other container materials that could be used in the construction of a pipe bomb [3][5][6][8][10]. To the authors knowledge no one has studied copper or brass pipes which are also readily available from hardware stores.

Aims and Limitations

The aim of this research is a preliminary investigation into the fragmentation of copper and brass pipe bombs, and the effect of changing the location of the initiator. It will do so using a rig designed to remove any effect of endcaps thus focussing solely on the fragmentation behaviour of the pipes. For analysis, the Fragment Weight Distribution Mapping (FWDM) and by comparing the fragmentation characteristics for both container materials with regard to two different initiator locations. The limitation is the small number of tests, meaning that statistically valid interpretation will not be possible. In addition, as the pipes were purchased from a local hardware store the dimensions varied between the copper and brass pipes which affected the internal volume and therefore mass of propellant between the two materials. But there should be sufficient data to indicate whether this approach and line of research warrants further investigation.

METHODOLOGY

In overview, the materials utilised in this study were copper and brass as both are readily available materials from local stores in pipe form. Similarly, single base propellant was used as the explosive fill. Pipe bombs were constructed using measured sections of pipe clamped between steel end plates (Figure 1a, b) bolted together by 4 long bolts. Whilst the bolts may interfere with some fragment collection, the use of the clamped end plates was to remove any contributory affects from a variation in the confinement arising from differences in end cap sealing. This was to enable direct comparison of fragmentation resulting solely from the differences in the experimental variables. For this particular feasibility study, the principle variables were the material and the location of the initiator. Each device was assembled using the same sequence of steps as detailed below.

Experimental set up

Eight trials in total were conducted; four copper and four brass pipes. The copper (42.1mm diameter, 1.3mm wall thickness) and brass (42.0mm diameter, 1.6mm wall thickness) pipes were cut to 120mm lengths. Prior to assembling the devices, each brass and copper pipe was individually weighed using a two-decimal scale, as detailed in Table I.

Each pipe was taped off at one end before being filled with VihtaVuori N310, which is a single-base smokeless powder, and weighed again (Table I). They were filled with as much powder as possible to avoid any air gaps, level with the top of the pipe,

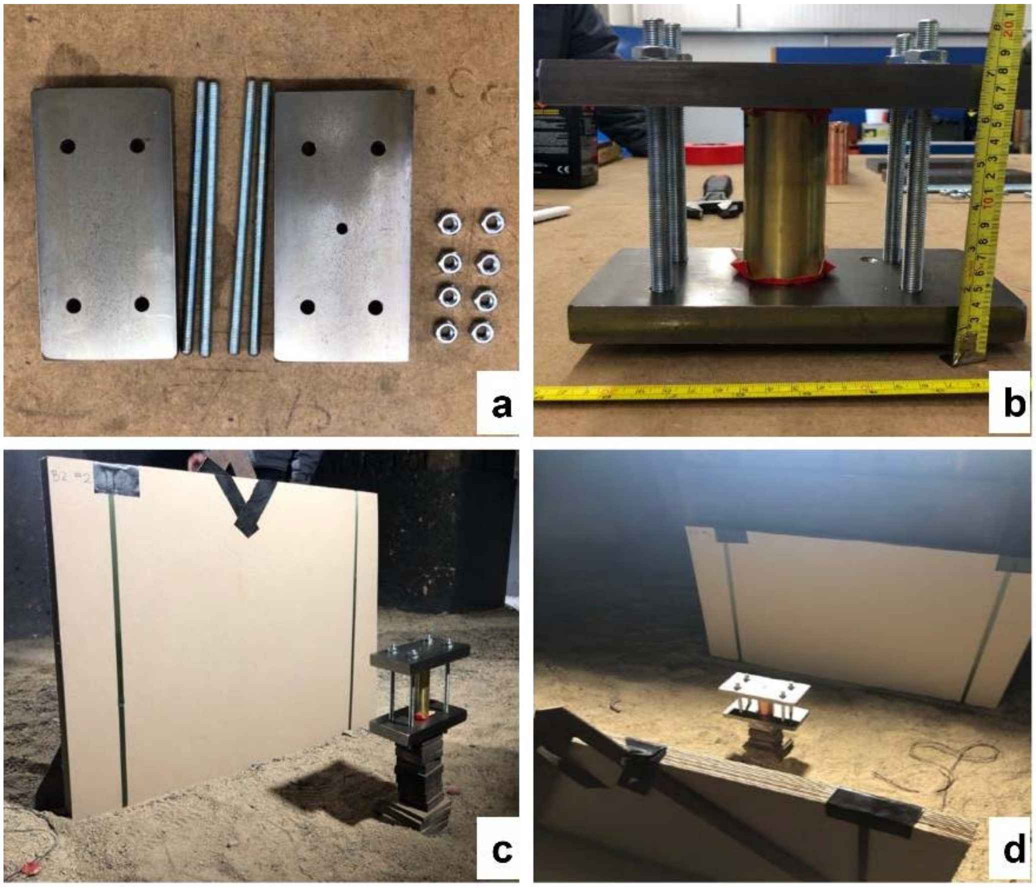

Figure 1. Experimental set up; a) end plate, rods and bolts used to clamp the pipes; b) assembled pipe bomb (without electric match); c & d) pipe assembly in place with strawboard packs on two sides

to try and ensure consistency between trials. Once filled and weighed, the open end of the pipe was sealed using plastic adhesive tape. The pipes were fitted into a clamp, which acted as end-cap replacements. The clamp consisted of two 200x100x25mm mild steel slabs that were held together by four 21cm long screw rods and eight nuts (Figure 1a). Each pipe was positioned in the centre of the clamp before being fastened into place as tightly as possible. To ensure the continuity of the tightness with which the clamps were secured, the same technician bolted all trials. The top plate had a 10mm drill hole through the centre, to enable the initiator (an electrical match) to be inserted into the pipe.

For each trial, the pipe bomb rigs were raised 26.5cm above ground level, with two packs of 10 strawboards placed on either side of the pipe. The strawboards were parallel to the long axis of the steel end plates with a distance of 50cm from the centre of the pipe to the first board. The strawboards were perpendicular to the floor with the height chosen such that the pipe was in line with the centre of the strawboards.

For each pipe material, two trials were ignited using mid-initiation and two trials were ignited using end-initiation. For the trials ignited using mid-initiation, the match head was fitted approximately 6cm deep into the pipe. For end-initiation trials, the match head was approximately 3cm deep into the pipe. Care was taken to try and ensure each match head was in the centre (radially) of the filled pipe, however some variability was inevitable.

Post firing, the strawboard packs were retrieved, and the floor of the containment building examined for loose fragments which were collected and bagged. The strawboard packs were taken to a separate lab, photographed and examined board by board with the fragments retrieved from each board for penetration depth and individually bagged for later analysis.

Analysis

Fragment Weight Distribution Mapping (FWDM) has been shown to be a useful tool for characterising the relative power of an explosive pipe bomb [3]. It has been implemented in past studies as a favourable method of analysis because it does not rely on the number of fragments recovered, meaning that it is possible to compare trials where there were varying levels of recovery success [5][8].

The x-component is calculated by dividing the weight of a single fragment by the total weight of fragments recovered from that trial. The y-component is calculated by adding the weight of a single fragment to the sum of all fragment weights heavier than it, and then dividing it by the total fragment weight recovered from that trial. Additionally, the y-component is calculated logarithmically to minimise statistical variations.

The x- and y-components are plotted in a graph and a linear regression is added to display the slope. The steepness of the slope is indicative of how violent the pipe explosion is. The mass of fragments recovered post-blast are related to the relative power of an explosion, with high-power events producing more small-sized fragments [5]. Therefore, when plotting a FWDM, more powerful explosions will result in having a steeper negative slope.

RESULTS

Strawboards

From examination of the strawboards, the fragment impacts were largely found in lower half (Figure 2). Only the mid initiated copper pipes produced fragments which went above the midline. There was no discernible pattern in the impact distribution. Penetration through the entire strawboard pack (10 boards) occurred for all the brass pipes. In contrast, for the copper only one of the end initiation, and 3 of the 4 mid initiation packs, were fully penetrated.

Collection

The collected fragments from all trials were photographed (Figures 3, 4) before being individually weighed. The fragments collected from each trial were weighed, and the weight of recovered fragments in comparison to the original pipe weight was calculated as a percentage. These values can be found in Table I. The fragment weights were then plotted onto a FWDM graph for each trial (Figures 5 & 6).

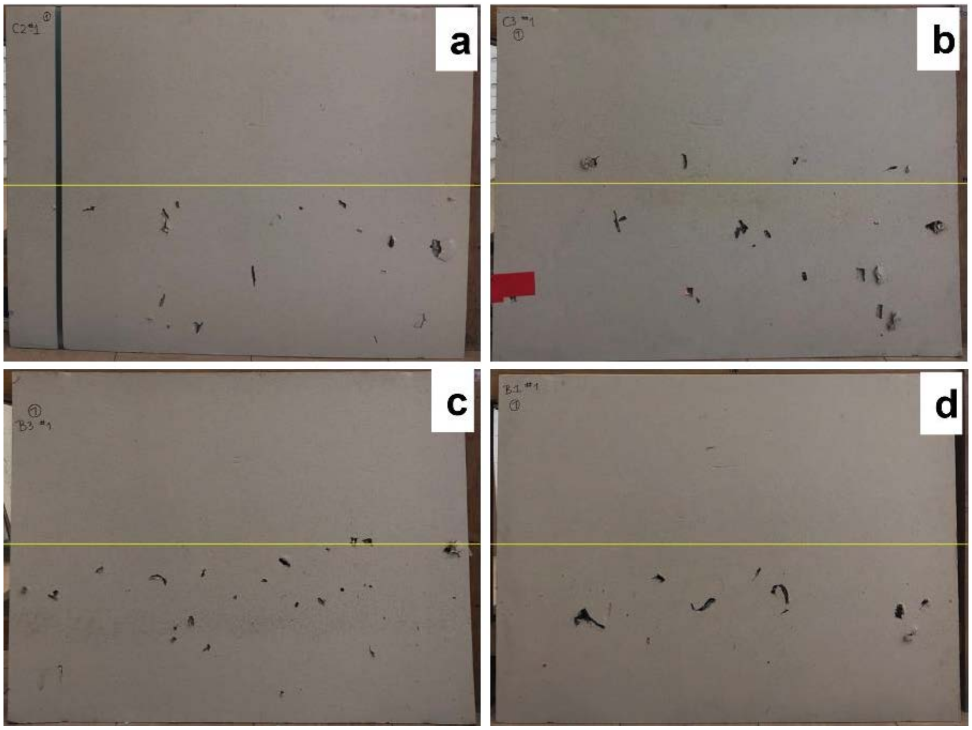

Figure 2. Photographs of the front face of strawboards, a) copper, end, b) copper mid, c) brass, end, d) brass mid

Figure 3. Copper pipe bomb fragments; a) #1 & c) #2 end initiation; b) #3 & d) #4 mid initiation

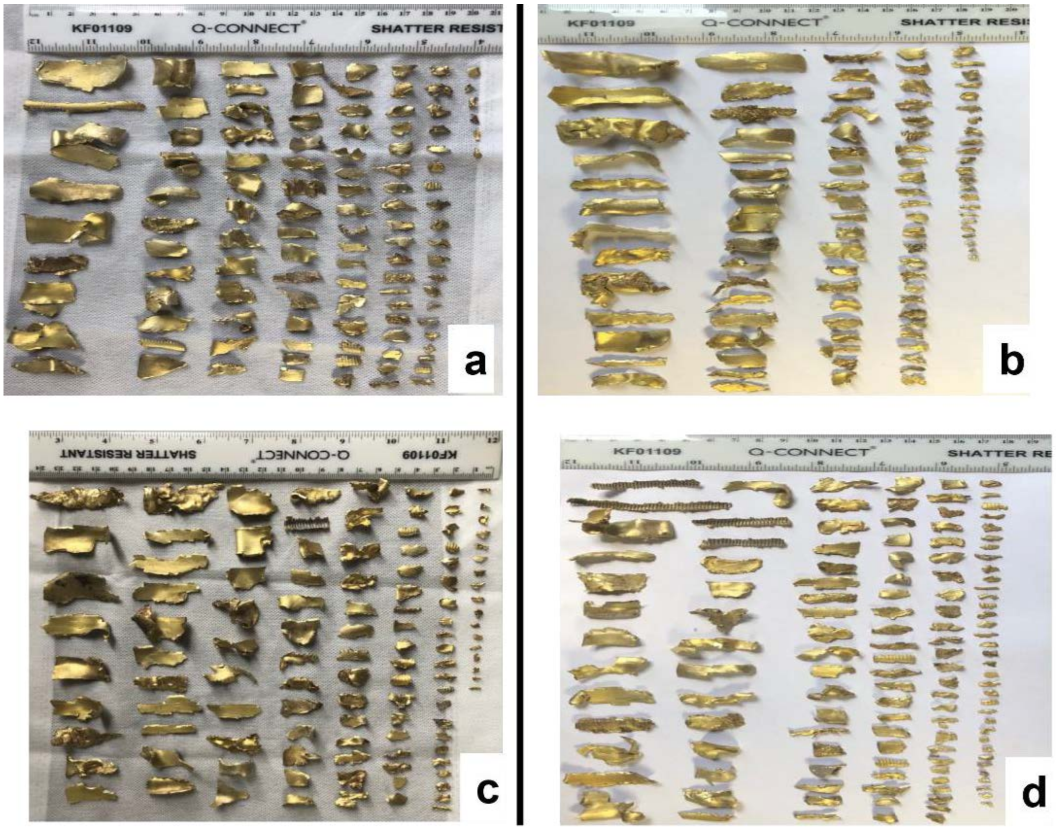

Figure 4. Brass pipe bomb fragments; a) #1 & c) #2 end initiation; b) #3 & d) #4 mid initiation

Pipe bomb and Fragment Data

Table I. Characterisation of Brass and Copper Pipe Fragmentation

Trial	Init	Mass pipe (g)	Mass filler (g)	No. fragments	% mass of recovered fragments	FWDM Gradient	R^2 for FWDM gradient
Copper #1	End	180.00	90.0	65	87.89	-14.07	0.836
Copper #2	End	179.81	90.0	82	88.19	-15.88	0.934
Copper #3	Mid	180.09	90.01	100	80.42	-22.51	0.921
Copper #4	Mid	179.69	90.01	127	85.15	-26.55	0.985
Brass #1	End	212.82	85.01	111	76.93	-17.58	0.969
Brass #2	End	212.78	85.00	115	85.46	-23	0.927
Brass #3	Mid	212.70	85.01	97	67.33	-12.50	0.989
Brass #4	Mid	212.72	85.01	129	67.35	-19.48	0.906

Fragment Weight Distribution Mapping (FWDM)

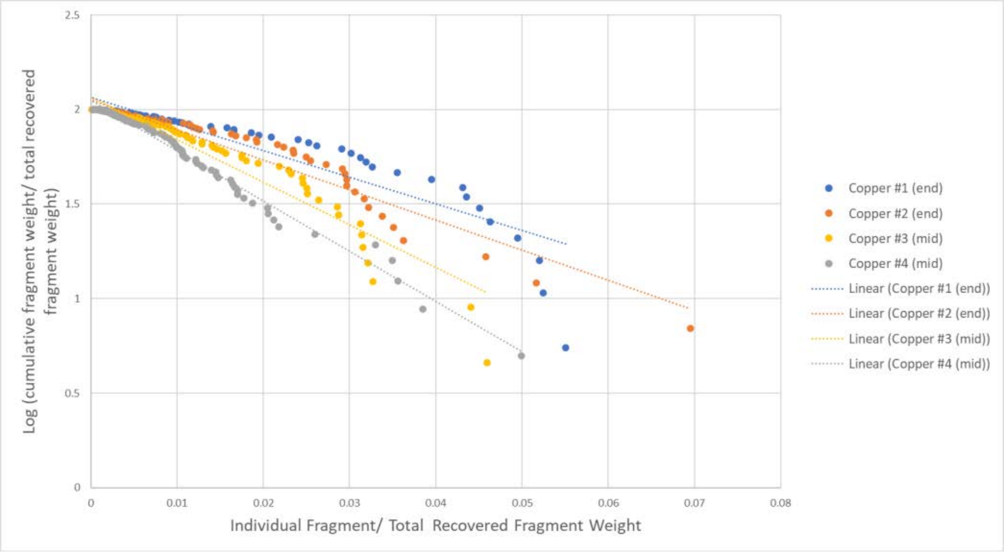

Figure 5. FWDM for copper pipes with end and mid initiation sites

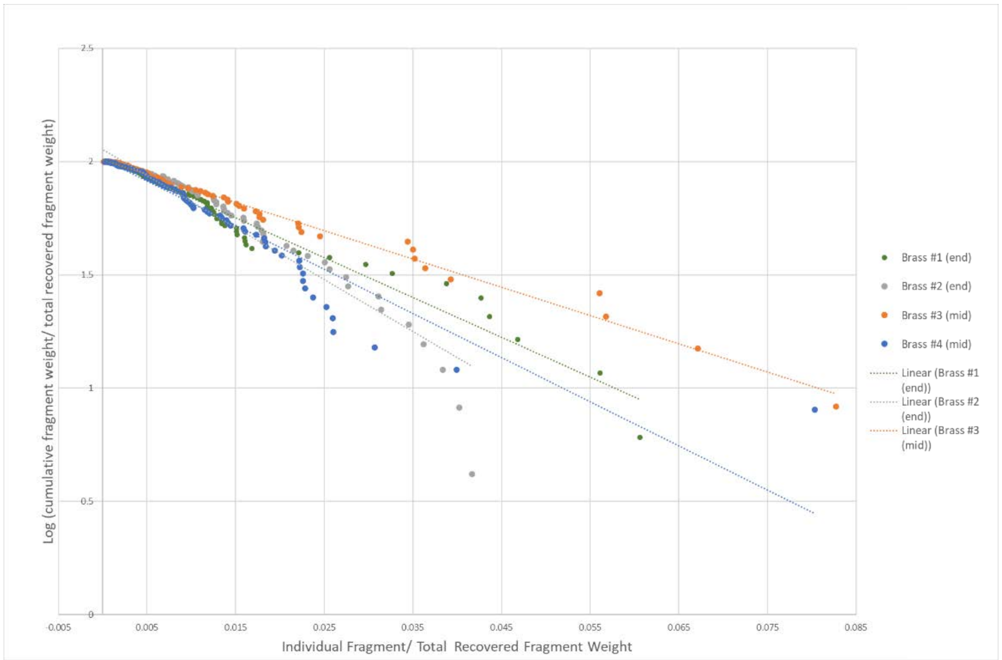

Figure 6. FWDM of Brass pipes with end and mid initiation sites

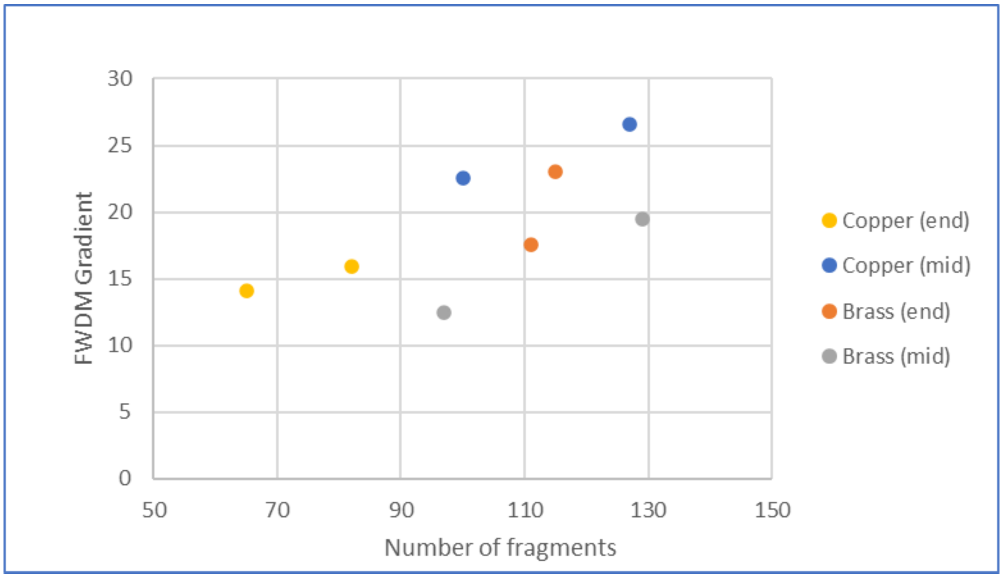

Figure 7. Comparison of FWDM (modulus) gradient with number of fragments for all the trials

ANALYSIS AND DISCUSSION

The use of the bolted plates to replace the endcaps has been trialled successfully. The bolts were not deformed (and were reusable), hence the clamping load on the pipe was maintained throughout the explosive event. This then indicates that the confinement from the endplates was consistent between tests and therefore this method is reliable for the study of pipe fragmentation. However, with the current approach the initiator may not have been placed at the planned depth and/or radial centre of the pipe. The initiator was pushed through the hole in the top plate into the pipe and the resistance produced by the packed filler could have caused the match head to curl or bend during insertion.

Despite the recovery boards being positioned on only two sides (the long axes) of the pipe assembly (Figure 1d), the proportion of fragments recovered is good, ranging from ~67 to ~88%. In two sets of serials there is remarkable consistency between the % recovered despite there being substantial differences in the number of fragments recovered. In the two sets where there are sizeable differences in %recovery it is noted that they tend towards the larger total number of fragments which is consistent with smaller (in size) fragments being lost more easily. The lack of symmetry in some of the trials with the number of impacts on the two strawboard packs is likely due to the non-central location of the initiator.

The majority of fragmentation impacted the lower half of the strawboards indicating the effects of gravity. The mid initiation of the copper pipes was the exception with some impacts above the centre line, and these had the greater FWDM slope values indicating higher energy. Similarly, in a previous project using this rig with a double base propellant fill and a detonator, the fragments were more evenly distributed across the strawboard (Wharton). Hence, maximum impact height could be an indicator of fragment velocity. Further study on the distribution is needed.

The difference in fragmentation resulting from the location of the initiator is clearly seen in copper in Figure 3. The greater number of fragments from the mid initiation can be attributed to a more efficient burn of the propellant before the copper pipe ruptured. This can also be inferred from the higher value of the (modulus of the) gradient of the FWDM for the mid initiation location compared to the end (Figure 7). In contrast, there is less differentiation in the number of fragments recovered from the brass pipes. This indicates that in both end and mid cases, the higher strength brass maintained structural integrity for longer enabling similar burning of the propellant. This again is seen in the FWDM with less clear distinction in the gradients (Figure 7). In both the copper and brass pipes however there are similarities in the fragment shapes, with the mid initiation resulting in much more uniform fragments than from the end initiation. This indicates a more uniform radial expansion of the pipes prior to rupturing when the propellant was ignited from the middle. This was seen in the impact points on the strawboards. For the copper a linear spread pattern was produced from mid-initiation but random for the end initiated.

All the brass fragments penetrated through the strawboard pack. However only 4 of the eight packs were fully penetrated by the copper fragments; 3 from the mid- and 1 end-initiated pipe bombs. As copper is softer it would have less penetrative ability that the brass, however direct comparison is difficult due to the difference in propellant mass and wall thickness, therefore kinetic energies. There is also no clear relationship to the FWDM gradient as one of the brass pipes had the lowest value gradient. But Oxley et al [5] reported similar (penetration depth vs FWDM gradient) behaviour for all steel samples so it is more complicated than solely due to material properties.

CONCLUSIONS

In summary, a total of eight pipe bombs, made of both copper and brass, filled with single base propellant, were ignited with an electric match positioned either mid- or end- of the pipe. A rig to study solely pipe fragmentation, with no confounding effects of endcaps, was successfully utilised, although its suitability for higher order explosives is not yet clear. The objective of this research was to see if there were differences in fragmentation characteristics if a pipe bomb had been initiated using mid- or end- initiation. Additionally, it was aimed to identify any notable distinguishments in the fragmentation characteristics observed in brass and copper pipe bombs by visually examining the fragmentation spread. Despite limitations and restrictions, this research still managed to produce some insightful findings.

For the copper pipes, the fragmentation was affected by the position of the initiator, with the mid location producing a greater number of fragments consistent with a greater conversion of the propellant mass. In contrast, no such clear relationship was seen with the brass pipe bombs. This likely indicates that the initiator location has less of an effect in stronger materials which are able to confine the propellant prior to rupturing when using low explosives. In both cases however the mid initiated pipe bombs produced more uniform fragments than the end.

Further work is needed to characterise the fragmentation of copper and brass pipe bombs.

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