A Review of the Mallet Impact Test for Small Scale Explosive Formulations

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Abstract:

Development of new explosive formulations begins with the generation of only a few milligrams of material which is investigated using a number of small scale tests such as DSC, TGA, response to flame, mallet impact (mallet friction either glancing or direct blow) to determine whether the formulation is safe to scale up to 10 g. The latter of these tests, mallet impact, can be particularly subjective as the result is directly influenced by the operator carrying out the assessment. Not only can there be a change from one operator to another but there can also be a change in the force applied during each strike potentially leading to inconsistent results. This study highlights this encountered variation and assesses the load applied by a variety of operators with varying levels of explosive experience. This paper also proposes the use of a small scale laboratory based impact test which would provide improved confidence in the assessment of impact sensitiveness of explosive formulations and assist in justifying whether a formulation can be taken to the next scale. A small scale version of the BAM impact test (EMTAP Test 43) has been devised that allows the comparison of the sensitiveness of small scale formulations relative to RDX (8.7 J, EMTAP Test 43B) whilst also ensuring a reproducible result.

Keywords: impact test; small scale explosive formulations

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1 Introduction

Before explosive formulations can be manufactured, testing of small batches is carried out. These small scale tests include Differential Scanning Calorimetry (DSC), Thermal Gravimetric Analysis (TGA), response to flame and mallet impact. This allows materials to be selected efficiently, without having to make large quantities of material that might be sensitive. This screening approach helps to identify which means of initiation stimuli the energetic formulations are susceptible to and inform the possible application of a material. These test results indicate and provide a degree of confidence on whether the energetic composition is safe to handle and scale up beyond the milligram scale to allow further assessment by means of response to electrostatic discharge, impact tests, temperature of ignition and vacuum stability. At Cranfield University, the mallet test is used to evaluate a material's sensitiveness to impact and friction. However, unlike chemical compatibility tests that have been well reported [1] there is a lack of literature reports available which focus on the validity of the commonly used mallet impact test. This study aims to discuss this test and highlight its advantages and disadvantages.

As discussed by Bowden and Yoffe, an explosion in a liquid or solid may be brought about by mechanical means such as impact [2]. The initiation mechanism associated with impact is hot spot formation. A hot spot can be formed in several different ways including adiabatic heating, friction between the explosive crystals or by viscous heating of the flowing explosive as it escapes from between the impacting surfaces, all of which consequently can lead to thermal decomposition of the solid or liquid [2].

Impact testing is carried out to simulate the effects on a sample of explosive being nipped and crushed between two metal surfaces [3] and is usually carried out multiple times, often hundreds, to gain reliable statistical data on the impact sensitiveness of the explosive. Often, during the early stages of energetic formulation development, there is insufficient material available to complete the necessary series of tests and therefore a ‘reduced version’ is carried out to provide initial indications on the impact sensitiveness of the material. At later stages in development the UK Rotter test (EMTAP test 1A [4]) or a similar drop weight test such as the Bundesanstalt fìr Materialprìfung (BAM) fall hammer (EMTAP test 43 [4]) is used.

In the Rotter test the explosive is placed in a brass cap which is then placed on the anvil and housing. The sample is spread evenly over the pip surface by rotating the cap on the anvil. The anvil housing is then slid under the machine ready for the drop weight to be lifted to the desired height and dropped onto the anvil. A gas measuring burette is used for quantifying the gas output of the reaction and in a normal test of 50-shots, a Bruceton staircase procedure is used with criteria for a “go” response outlined in the Energetic Materials Testing and Assessment Policy Committee (EMTAP) manual [4]).

In the BAM fall hammer test the sample is placed between two coaxially arranged steel cylinders held in place by a guide ring. This is then placed onto the intermediate anvil which is situated on the main anvil which sits on a cast steel block. The drop weight is held above the sample at prescribed heights using guide rails and a release mechanism. Different masses of drop weights can be selected depending on the required impact energy. The limiting impact energy is defined as the lowest impact energy that results in an “explosion” in at least one drop at that energy when at the next lower energy no explosions result from a set of six trials.

It is known that with the BAM test the operator can be subjective when recognising a “go” or “no-go” by observing the resulting flash, smell, or sound [3] but the impact energy is determined by the drop weight and the drop height at given increments and so is standardised for each material tested as the weight is allowed to fall under gravity. Often with only small quantities of material available at the earlier stages it is not possible to perform these tests at all and this is why the mallet test is used as it only requires approximately 40 mg to complete. The mallet impact test is a useful tool to identify the sensitiveness of new energetic compositions shortly after they have been produced, reducing the risk that the operator is exposed to by quickly identifying those materials that are more sensitive and allowing the appropriate handling precautions to be implemented.

There are inherent problems when allowing the operator to have such a great influence over a test as experienced with the direct blow mallet test. There is no set amount of force for the operator to strike the explosive sample with and so it is left to the judgement of the operator to try and maintain testing consistency. This could lead to a variation in the handling properties reported for a single material by different operators within an organisation.

This paper presents the variability of force input from ten participants and will discuss the potential for the use of a laboratory small scale impact test based on the design developed by Bundesanstalt fìr Materialprìfung (BAM) [5] to standardise the impact energy and allow for a reduced bias in the screening of new explosive formulations at Cranfield University.

2 Experimental

2.1 Equipment

In the mallet impact test a small quantity of explosive material, typically 10 mg, is placed on a steel anvil and hit with a steel mallet. The mass of the steel mallet and anvil were approximately 145 g and 650 g respectively (Figure 1).

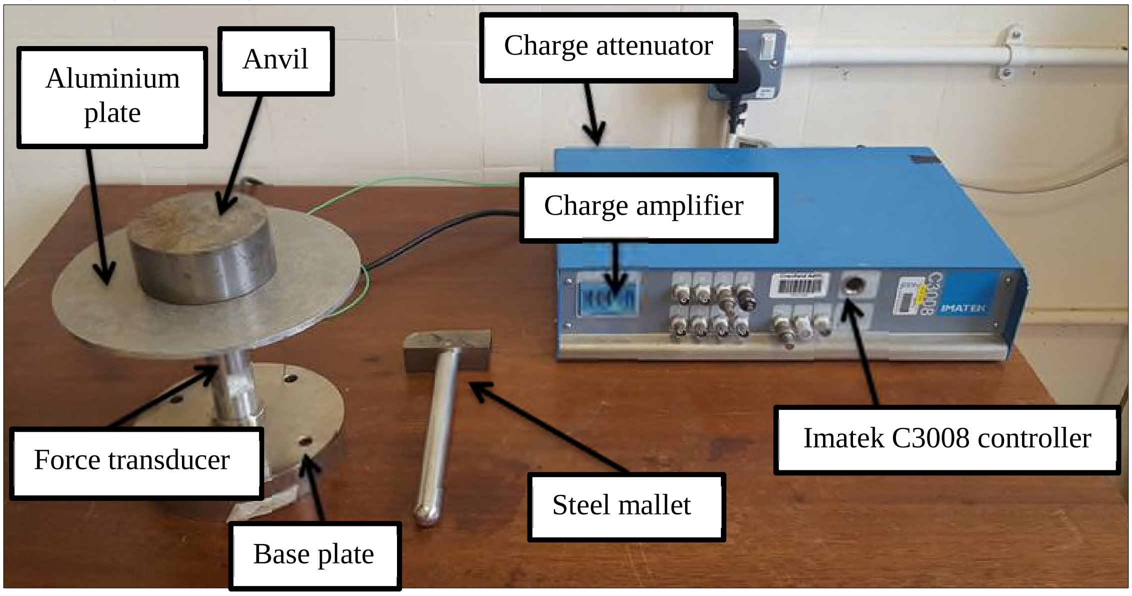

Figure 1: Arrangement of testing equipment to measure the force applied to an anvil when hit with a steel mallet.

The mass of the anvil had no influence on the peak force values recorded as the force transducer was zeroed before testing started. The Kistler 9031A transducer was attached to an aluminium plate where the anvil was positioned above. The base plate was present to give stability to the set-up. The transducer was connected to a Kistler charge attenuator 10:1 type 5361A that, in turn, was connected to the Imatek C3008 data acquisition controller. The C3008 controller had a Kistler charge amplifier type 5041 which could be used for selecting 6 kN, 60 kN or 600 N output. The C3008 was connected to a laptop, via Ethernet cable, to enable visualisation and recording of the data.

2.2 Software

The laptop was running ImpAcqt software, version 3.0 (build 5). The channel setup was configured so that the range was ± 60 kN; this also had a calibration file associated with it which was updated prior to testing. The data acquisition was set to capture 1000 data points and to record a time of 25 ms. The trigger mechanism was selected to be a force at a level of 0.706 kN or greater which was high enough not to be falsely triggered and would ensure that data capture started when the anvil was struck.

2.3 Participants

Ten participants from a variety of backgrounds were chosen to take part in the test. Six of the participants are explosive workers but have never carried out mallet testing and one participant was a non-explosive worker. Out of the remaining three, two have extensive experience in performing the mallet test and one has completed a limited amount of testing previously. Participants were made aware of the aims of the study and may have different preconceptions of the force required when carrying out the mallet test.

2.4 Testing

The aim of the test was to measure variation in the force applied by individuals and therefore no explosive powder was used during the testing. All participants, regardless of background and prior knowledge, were given the same brief and demonstration. This was to strike the anvil by moving the mallet towards it using the wrist for momentum and not the elbow or shoulder and to be as consistent as possible. The transducer was armed before each hit and the data logged by the computer. This was repeated for 50 hits per participant.

2.5 Analysis

The mean of each participant's recorded peak forces was calculated and a standard deviation for the set of data was produced. The sample standard deviation method was used to generalise the results to the population and was taken to two standard deviations. The results were analysed by ANOVA (Analysis of Variance) to determine if a statistical difference exists for the peak forces between individuals.

3 Results and Discussion

Table 1 displays the mean and standard deviation impact results for each participant and the corresponding graph, Figure 2, presents a graphical display. Due to the large amount of data gathered not all of it could be presented within, therefore the raw impact data is only available directly from the corresponding author.

Table 1: Mean and standard deviation results for peak force achieved by each participant.

Participant	Mean (kN)	Standard Deviation (kN)
1	11.81	3.56
2	10.87	2.74
3	18.88	4.32
4	7.33	2.00
5	17.94	4.05
6	24.30	5.24
7	12.71	2.53
8	11.36	3.23
9	16.13	3.80
10	15.79	4.31

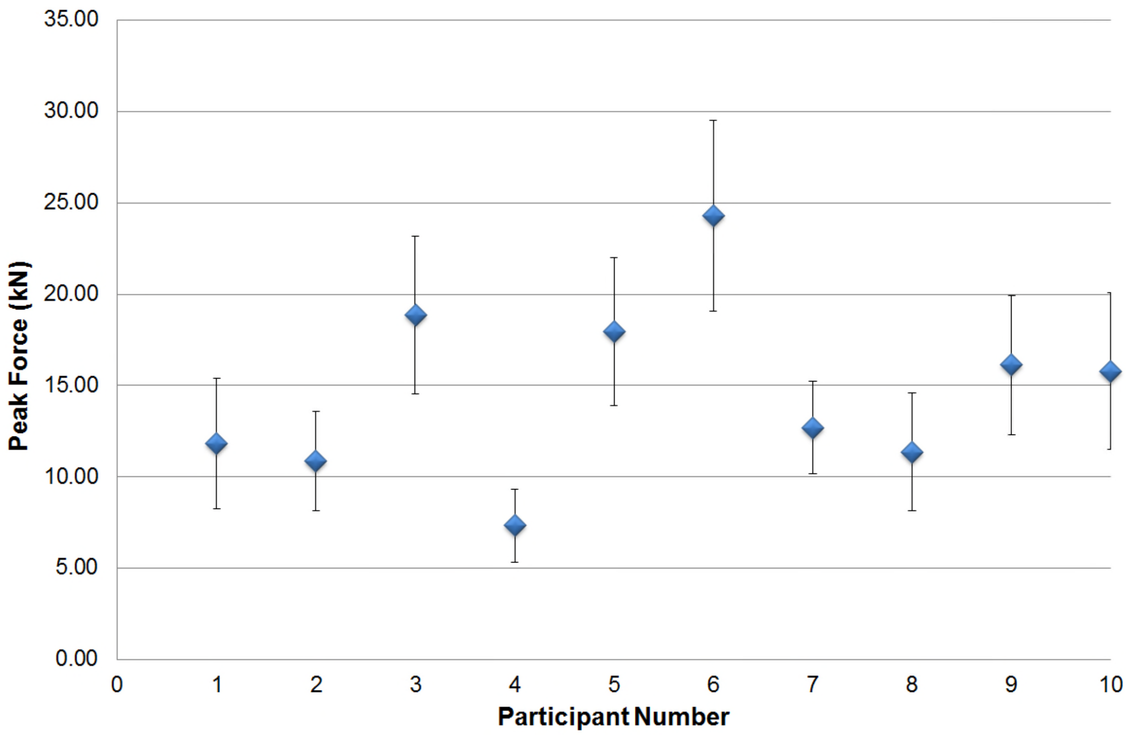

Figure 2: Mean peak force values for each participant with standard deviation error bars.

The peak force values were analysed in an effort to establish the degree of variation seen within each participant. There are many factors that influence the ability and accuracy to compare results between the participants, such as height, strength and experience. However that said, it can be clearly seen that there is a spread of peak forces achieved between 6 kN and 29 kN. As discussed, it is no surprise that the peak forces vary between participants, therefore this paper will concentrate on the degree of inconsistency seen within an individual as this will affect the reported sensitiveness properties of a material if it is tested by the same person.

The standard deviation varies depending on the individual, for example, participant four had the lowest deviation of 2.00 kN and had previous experience with pyrotechnic compositions and tamping down mixtures using a hammer. The user is accustomed to applying less force with a mallet in these situations and to a greater consistency of force.

Participant six was a non-explosive worker and gave the highest mean and standard deviation values (24.30 kN and 5.24 kN respectively). The high peak values may be a result of the lack of understanding for explosive handling procedures and the care that is needed and so when asked to simulate hitting an explosive the participant would not have known the force generally required to initiate an explosive.

The null hypothesis for this research is that each individual will have a similar variation in their peak force values; this is due to the individuals being drawn from the same population, so the variation should be the same for all individuals. To statistically investigate if the null hypothesis should be accepted or rejected ANOVA was used. The data in Table 2 shows that the F value ($F(9,490)$) is 351.33 and when this F value is applied to an F-distribution at $p = 0.05$ critical value, the F value far exceeded the F critical value of 1.8989. Therefore the null hypothesis must be rejected, as there is significant difference between individual's variation in the population.

Table 2: ANOVA analysis displaying the sum of squares, degrees of freedom, mean square, F value, P-value and F critical value.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10786.58	9	1198.508	351.33	2.3E-207	1.8989
Within Groups	1671.542	490	3.411301			
Total	12458.12	499				

If the sensitiveness to impact of an explosive was being reported by these participants, it is likely that several different conclusions would be drawn based on the amount of force the explosive would be subjected to. It would be reasonable to assume that participants one, two, seven and eight would report the same findings, however participant six would most likely report a greater number of “go’s” due to an increased amount of force. Participants nine and ten, and three and five respectively are likely to report similar findings based on their average peak force and standard deviation. Participant four is the only person who may report more “no-go’s” than any of the other participants due to the lower energy input from their strikes.

The results from this testing may not reflect the true force experienced during explosive testing though, this is due to the set-up of the equipment. Under normal circumstances the anvil is placed on the benchtop and was raised by 140 mm for this experiment to be carried out. The operator usually strikes the anvil in quick succession, however due to the need to re-arm the transducer after each strike this was not possible and so the effect on the peak force experienced by repeating strikes in this manner is unknown.

Based on the factors discussed above, this approach is not faultless and could lead to a sensitive material being inadvertently scaled-up. Therefore a laboratory small scale impact test machine based on the BAM fall hammer has been devised and a test procedure based on the EMTAP test 43 [4] has been developed by Cranfield University to standardise the impact energy and allow for a reduced bias in the screening of new explosive formulations. The test apparatus is shown in Figure 3 and utilises the preliminary 10-shot trial in the EMTAP Test 43B [4] using the Bruceton up-and-down run to determine energy required for 50% probability of ignition. By using a 10-shot test, the quantity required for assessment is significantly reduced to under 1 g (based on a density of <2.0 g/cm3), therefore the amount of formulation generated can be kept to a minimum whilst potentially also providing a sufficient degree of confidence in the results.

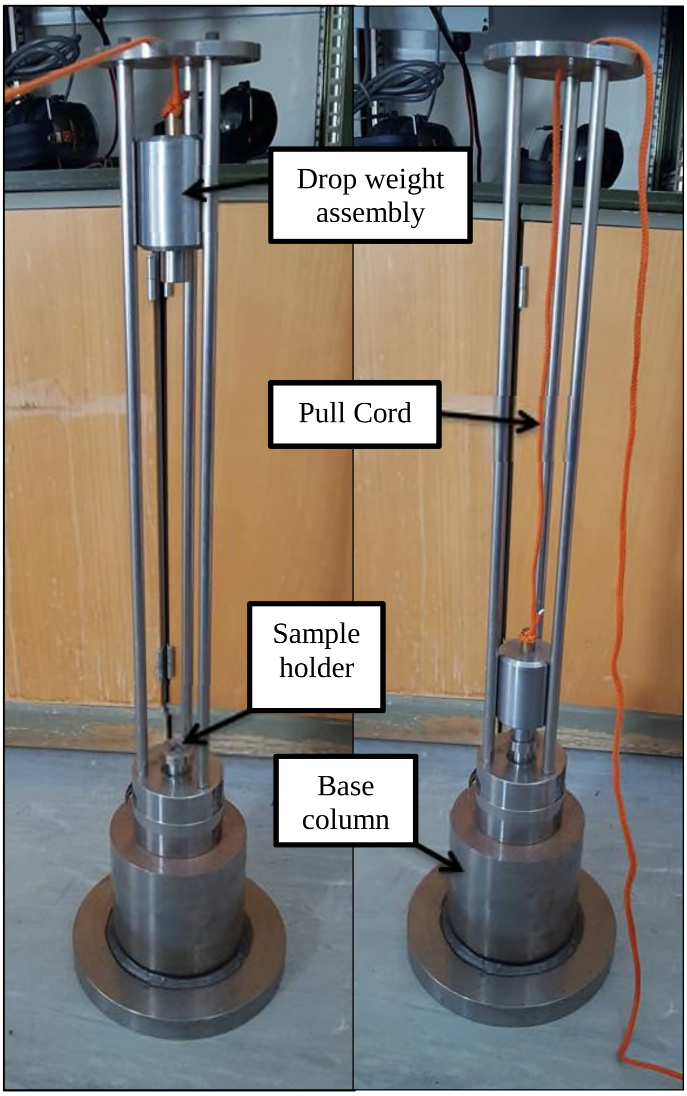

Figure 3: Small scale impact test apparatus at Cranfield University.

The aim would be for this machine to be used in a laboratory to test small quantities of explosives during the early stages of novel formulation development. This would be most useful for hazard assessment of small scale energetic materials and minimise the need to transport the samples to the test house.

4 Conclusions

This study has shown that there is variation in the force input by each individual when striking a mallet against an anvil and that the amount of force applied within the test is additionally operator dependent. Therefore there is potential for use of a standardised test which would help reduce the operator bias with regards to the impact energy. This in turn would improve confidence in the assessment of impact sensitiveness of explosive formulations and assist in justifying whether a formulation can be taken to the next scale. A further study will be carried out utilising this small scale impact test to assess a number of neat explosives and other energetic material formulations of different sensitiveness. These results will then be compared to those achieved using the larger scale instrument and results obtained from the mallet impact test.

By implementing a standardised small scale impact test a database could be compiled, allowing comparison of results between known explosives and novel explosive formulations. If this small scale test is used it may lead to an improved reliability of the reported impact sensitiveness for new energetic compositions, which would reduce the misinformation that may lead to irrelevant development work, putting operators and facilities at increased risk, should the material be deemed not suitable at a later stage. With this improved reliability it would allow for a better judgement to be made for the handling precautions implemented before scale-up of a formulation is permitted, thereby improving safety.

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