8. New applications and training

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Blasting activities with fast-combusting energetic compositions in dimension stone quarries and for demolition of structural elements in civil engineering

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ABSTRACT: In some cases of resources extraction, as well as in construction at industrial and urbanised territories, commercial explosives are not safe enough for the surroundings with regard to the generated fly-rocks, air-blast, toxic fumes, seismic waves and vibrations. The main reasons for these harmful impacts of explosion are the velocity and the mechanism of the chemical reaction of explosive decomposition. The authors shifted the focus of their research from detonating explosives to high-speed combusting energetic materials. The major focus of the study is the production of low explosive non-detonating mixtures from long-term stored smokeless gunpowders and ammonium nitrate prills in different configurations, and popular pyrolant compositions. The samples of different cartridge casings, filled with non-detonating propellant mixtures or pyrotechnic compositions were examined with two methods – measurements of the velocity of propagation and field tests. The application of waste single-base-powders and double-base-powders for creation of non-detonating explosive cartridges, suitable in dimension stone mining, as well as in blasting activities in areas with increased requirements was examined. *Keywords: non-detonating blasting cartridges, propellants, cautious blasting, dimension stone extraction, blasting demolition*

1 INTRODUCTION

1.1 About explosive chemical decomposition

The velocity of detonation (VoD) is the rate at which the detonation wave travels through the explosive charge. The higher this velocity, the greater the ‘force’ or the crushing effect of the explosive. Higher velocity explosives are better suited for blasting in hard rocks, and low-velocity explosives are appropriate for work in soft and cracked rocks. In general, ‘low-speed’ explosives tend to release gaseous products for a relatively longer period, and therefore exhibit better heaving effect. Detonation rates of different industrial explosives range between 2500-7500 m/sec. Detonation pressure is the pressure in the reaction zone when explosive molecules break down. The latter is an important indicator of the explosive’s ability to induce a good fragmentation (Mitkov 2010 (A))

Deflagration is a subsonic reaction of chemical decomposition of the explosives. It is typical for propellants and pyrolants, which could act on the solid medium by the pressure generated by gaseous products from chemical reaction. There is practically no shock energy generation. In reality, such an effect occurs when a charge of blasting gunpowder is ignited in an appropriately tamped blast hole (Shishkov & Stoycheva 2018).

1.2 About pyrotechnic compositions

In accordance with definition by (Boychev & Asenov 2020 B) pyrotechnic compositions are a substance or mixture of substances intended to produce special effects - heat, light, sound, smoke, gas, or a combination thereof, as a result of spontaneous exothermic red-ox reactions that do not require oxygen from external sources. The main ingredients are oxidiser and fuel (reducer). Various additional modifiers could be present in the mixtures, regarding needed effect. Depending on the speed of the chemical reaction, several different forms of chemical conversion could occur – thermal decomposition, burning mode, combustion, deflagration, atypical detonation and detonation. The factors that determine which form would develop are:

– chemical nature of the components;
– degree of dispersion;
– homogeneity of the mixtures;
– presence of impurities, especially moisture;
– type and power of the initiating pulse;
– location of application of the initiating pulse in the volume of the charge;
– quantity of the bulk mixture;
– density of the composition;
– degree of the confinement of the mixture;
– construction of the pyrotechnical device (Boychev & Asenov 2020 B)

High-performance propellants, imitation mixtures, photo mixtures, and so called "’lash powders’ are types of pyrotechnic compositions which are suitable for achieving a gas-generating high-temperature effect in a time range of milliseconds.

In 1992, Kuwahara and Ochiai introduced the term ‘pyrolants’. These are materials, typically including metallic or non-metallic fuels (Al, Mg, Ti, Si, B, S) and inorganic [Ba $(NO_3)_2$, $NaNO_3$, $KClO_4$] and organic [C_2Cl_6, $(C_2F_4)n$] oxidants, in the combustion of which emit bright light and condensed products (hot gases). They are characterised by a high enthalpy of combustion (1-30 kJ/g) and a density in the range of 2-10 g/cm^3.

1.3 About waste smokeless gunpowders

It is well known, that single based propellants (SBP) generally are pelletised or extruded porous grains in different sizes and shapes, which usually contains 93 – 97 % pyroxylin and 3 – 6 % additives like dibutylphtalate or dimethylacrylate or camphor (phlegmatisers), diphenylamine (stabiliser), KNO_3 or K_2SO_4 (pore-forming salt), graphite, remaining alcohol-ether solvent, etc. Double-based propellants (DBP) are mixtures of nitrocellulose (NC), 2-8 % additives (similar to these in SBP) and nitro-esters, usually nitroglycerin (NG). The content of NG is about 10 - 38 %. The boiling point of NG is 50 ºC. DBP might have higher energy content than SBP. Their caloric content varies depending on their types between 3800 and 5200 kJ/kg. The grains of DBP are also with different sizes and shapes. They could be compact or porous regarding the type. The prices of waste SBP and DBP in Bulgaria are around 0.10 EUR/kg (Shishkov & Stoycheva 2018).

The authors focused their researches to laboratory experiments for combustion rates and field tests for explosive performances of high-speed combusting energetic materials on the base of pyrotechnic compositions and secondary propellants.

2 EXPERIMENTAL SETUP

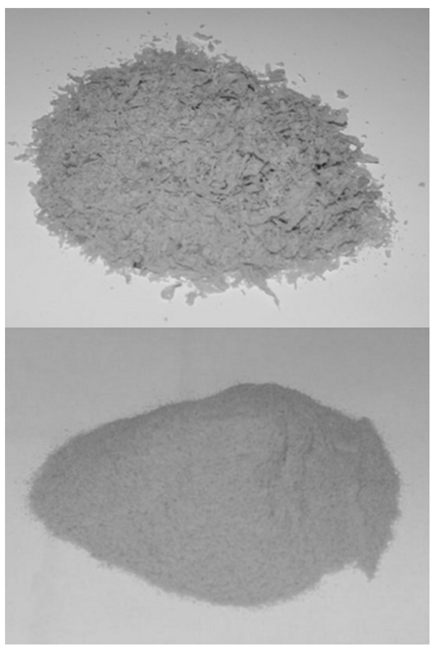

Figure 1. Top - general image of DBP and SBP type. Below - after grinding in the mill.

The propellants, investigated in this study are nitroglycerine gunpowder (further referred to as

DBP) with the brand name NDT-3 18/1 and the 18/1-branded pyroxylin SBP. The test specimens are in form of long tube-shaped bodies, and are further processed by grinding after their extraction from decommissioned ammunitions (Fig. 1). The size of propellant grains should be similar to the size of the porous prills of ammonium nitrate as prevention against stratification of the ingredients.

Three different compositions were designed and mixed for further research at the laboratory testing field, at a stone quarry, and for demolition of hardened concrete:

– Mixture #1: flash-powder composition 68% KNO_3 + 32% Al (dark) with Oxygen Balance = -1.55%
– Mixture #2: 50% grinded SBP + 50% NH_4NO_3 prills with Oxygen Balance = -11.00%
– Mixture #3: 40% grinded DBP + 55% NH_4NO_3 + 5% Al (dark) with Oxygen Balance = -8.65%

Ready compositions were loaded in aluminium testing tubes, plugged at both sides (Figure 2) with the following dimensions:

– 320 mm / ф10 mm inner diameter/ 1 mm wall thickness
– 320 mm / ф20 mm inner diameter/ 1 mm wall thickness

Each pipe has 3 drill holes: the first one is for electric ignition, the second one is for sensor №1 (located 3 cm from the first hole) and third for sensor №2 (located 25 cm from the second hole). The ignition of the samples was made using regular commercial electric bridge-wire igniters with smooth burning fuse-head for fireworks and professional pyrotechnic purposes, manufactured by ‘META_PYRO’ s.r.o., Czech Rep.

Figure 2. Test samples - loaded and plugged aluminium pipes with electric igniter.

The velocity of deflagration was measured by two different devices:

– with apparatus Trio Chronos, manufactured by TRIO Electronics Ltd., Rep. of Serbia, using optic fibre sensors.

Figure 3. apparatus for measurement of VoD optical sensors.

- with apparatus CNT-66 Pendulum, manufactured by BRL Test Inc., USA, using contact wire impact sensor.

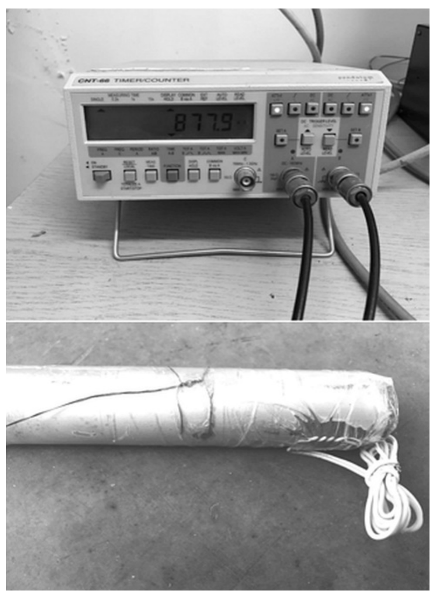

Figure 4. Apparatus for measurement of VOD and sample with impact sensor.

Sensors and the electric starter were connected to the testing equipment. All laboratory experiments were done at the laboratory testing area of Minproekt - Dragichevo.

3 RESULTS AND DISCUSSION

The velocity of explosive decomposition for the different samples are given in Table 1.

Table 1. Experimental results for velocity of explosive reaction of different samples.

Sample number	Inner diameter of the test tube (mm)	Mixture type	Velocity of reaction (m/s)
1	10	#1	522.31
2	10	#1	10.88
3	10	#1	224.46
4	10	#2	202.35
5	10	#2	289.15
6	10	#2	250.82
7	10	#3	348.71
8	10	#3	284.26
9	10	#3	304.62
10	20	#1	1625.32
11	20	#1	747.39
12	20	#1	698.75
13	20	#2	491.71
14	20	#2	410.34
15	20	#2	463.16
16	20	#3	598.21
17	20	#3	482.76
18	20	#3	554.16

The results show that pyrolant Mixture #1 (flash-powder) provides to higher velocities of explosive decomposition and in bigger diameters of the charges is inclined to pass from combustion - to detonation, which is not acceptable to industrial requirements for low-explosive charges. Propellant containing compositions Mixture #2 (with SBP) and Mixture #3 (with DBP) are increasing their velocities of deflagration with enlarging the diameter of the charge, but samples containing DBP and Aluminium are releasing more energy, as expected.

After laboratory experiments, some field tests at the stone quarry were conducted. Few boulders with similar shapes and sizes were selected for testing of blast-splitting capabilities. Regarding the risk of transition from deflagration to the detonation of 'flash powder composition' (Mixture #1), small charges of 0.050 kg was poured without compaction in well-plugged paper tubes with inner diameter 25 mm and 150 mm length. The conditions for possible shock wave generation and detonation of that sensitive flash-compositions are higher density, bigger diameters, and larger volumes of the charges. The authors decided to use petards with a smaller diameter than the blast-hole. The existing air gaps between the decoupled charges and the walls of the bore-hole prevent increasing the pressure to dangerous rates for transition from combustion to detonation. Very low concentrations of an explosive charge in the drill-holes between 0.10 kg/m^3 and 0.15 kg/m^3 has to be achieved for split-blasting without undesired crack propagation. This is the reason, in the case of bore holes longer than 1.0 m, multi-deck charges are a better choice for smooth blasting.

Figure 5. Splitting of a boulder with one charge of 0.05 kg. Mixture #1 in single blasthole with length 0.60 m.

All petards were equipped with traditional fuse-head electric igniters, usually applied in professional fireworks events. Each device was protected with water-resistant polymer foil. These electrically controlled low-explosive cartridges were used like bottom charges in single or double parallel blast holes, drilled in stones with volumes between 4 - 6 m^3. The selected rock boulder samples were free standing (with free surfaces) and similar shapes. Proper stemming has a leading role in the quality of the performance of the non-detonating explosives in the blast-splitting

Figure 6. Propellant based cartridges with Mixture #3 in plastic foil bag.

activities. When we prefer to deprive from the advantage of the supersonic pressure wave, which causes a sharp impact on the rock, we have to ensure long enough retention of the explosive gases pressure in the drill hole.

Very good results were achieved after treating the boulders with a single charge of the aforementioned petards in a short borehole with a diameter 45 mm and length 0.60 m. A smooth-walled cleft was obtained throughout the volume of the stone. No additional cracks were observed in the area of the blast hole (Figure 5).

After the experiments with flash powder composition, further tests with receipts containing secondary smokeless powder were conducted. For the field tests at the stone quarry Mixtures #2 and #3 were used for the preparation of 0.050 kg and 0.100 kg charges in thin plastic bags fitted to the diameter of the drilled holes (Figure 6). As it is known, smokeless gunpowders have so-called progressive combustion, the speed of which depends on the pressure in the burning area, the power of the ignition pulse and the surface of initial ignition. For this reason, the authors preferred to ignite those propellant charges not directly by electric igniters, but with small pyrotechnical boosters. 3-4 g of pyrolant Mixture #1 and electric igniter was used for the preparation of each petard, which was intended to provide the boosting energy for massive inflammation of our foil-cartridges with Mixtures #2 and #3. As it is described by Boychev & Asenov (2020 A) during deflagration of flash-mixtures, fine metal particles of the fuel are evaporating and due to the high temperatures and pressure, they transition into a plasma state. Driven by the high pressure of the hot gasses, the sparks and plasma are penetrating deep through the gaps between the bigger grains of the propellant. In this way, several layers are ignited simultaneously in the depth of the charge. The combustion of propellant mixtures starts with a higher initial rate and pressure, which in the conditions of tamped drill-hole contributes to a shorter period of increase of the velocity of the explosive reaction. In practice, a higher deflagration rate means a larger amount of hot gases, emitted per unit of time. This affords better performance of the low-explosive.

New experiments were performed with charges of Mixture #2 (in plastic bags) on boulders. Pyrotechnical booster was loaded first on the bottom of the 0.60 m deep drill-hole. Plastic

Figure 7. Splitting of a boulder with one charge of 50 g Mixture #2 in single blasthole with length 0.60 m.

Figure 8. Splitting of rock body with two parallel boreholes. Effects from preloaded bottom charge of 300 g. Mixture #3 and decked second charge of 150 g. Mixture #3 in every single blasthole with length 1.80 m.

cartridge with 0.050 kg of the tested composition with a diameter close to the hole size was tightly inserted over the booster. Then, the blasthole was filled with reliable stemming. There was an excellent clean splitting of the stone after a low-noise explosion with a slight displacement of the two parts (Figure 7).

The last experiment was done for the extraction of a stone block with a volume of almost 8 m^3 by splitting from a rock body with three free faces. Taking into account more complex conditions for explosive influence, the authors preferred to use two longer bore-holes and cartridges from packed in a thin polymer bag Mixture #3. The length of the blast holes was 1.80 m. For better distribution of the energy of compressed gases, the explosive charge was separated into two parts with inert stemming between them and simultaneous ignition. Two handmade cartridges weighing 0.100 kg each with one electrically ignited pyro-booster were placed for bottom charge in every hole. They were well sealed with 30 cm semidry sandy-clay stemming. One pyro-booster, equipped with electric igniter and single cartridge of 0.100 kg Mixture #3 was used for the second decked charge in the blast-holes. The total explosive quantity of each blast-hole was 0.300 kg propellant mixture. Reliable inert stemming between charges and especially over the second charge to the mouth of the blast-hole assured so desirable condition for enough pressure of gaseous products. That guarantees as better as possible crack formation for splitting.

Although all measures have been taken to avoid detonation when using propellant composition, the combination of high-speed deflagration with too large volume of gases (generated by preloaded bottom charges) caused an unnecessary throwing effect and several additional cracks in unexpected directions (Fig. 8). This was a sign that a more precise calculation of the parameters of drilling and blasting was needed.

After field tests at the stone quarry, an in-situ experiment for fragmentation of hardened concrete inside the mixing barrel of the concrete truck was made (Figure 9). The processes for crushing of consolidated cement mixtures and non-reinforced concrete are identical to those in the fragmentation of rocks. In them, intense cracking can be caused even only under the influence of rapidly expanding

Figure 9. Concrete mixer – exterior and interior with consolidated concrete inside.

Figure 10. Loading of the charges inside the blast holes.

gaseous products. Experiments for blasting of consolidated concrete by non-detonating charges, without allowing deformations of the metal housing, are the next step in the study of the potential of low-speed energetic compositions for delicate blasting not only in the extraction of dimension stones, but also for special blasting works.

The available hardened concrete mixture was distributed along the entire length of the barrel, filling 37.2% of its total geometric volume. The remaining free volume of 62.8% was inconvenient, but sufficient to carry out preparation for special blasting works. Given the specific conditions of the site and the irregular shape of the concrete body, which was located in the lower part of the barrel, the blasting for swelling the concrete was carried out in stages in several sectors to preserve the structural integrity of the mixer.

For the design of the blasting-plan, the concrete body was considered similar to a dug foundation of non-reinforced concrete. In order to achieve a more gentle blasting effect with the successive opening of free surfaces, a model of the bench blasting by the method of small charges was provided. Considering the delicate technical conditions of the site, an opportunity was sought for a choice between explosives that do not detonate. In this particular case, a pyrolant explosive was chosen. Flash powder composition (Mixture #1) provides a relatively large volume of gaseous products per kilogram of explosive and a sufficiently short period of rate increase to deflagration. Small charges of 0.050 kg was poured without compaction in well-plugged paper tubes with inner diameter 25 mm and 150 mm length. Blastholes with diameter of 30 mm and lengths from 0.35 to 0.60 m were used. Charge construction – column type.

Figure 11. Fragmentation of the concrete after blasting.

In order to achieve sufficient cracking of the concrete body, the relative distance between the individual blast holes should have been the same. A staggered layout of the blasting pattern was chosen. Due to the fact, that non-detonating pyrotechnic charges were used, the closer spacing of 0.30 m was determined. Electric igniters for professional pyrotechnic purposes, connected in a series circuit, were preferred as the most suitable means for inflammation. Their number was determined depending on the blasting rounds parameters. The main goal was to avoid overloading the structure of the concrete-mixer caused by instantaneous expansion of the solid material during blasting. Manual loading with an individual approach to the blast holes was preferred. Charges were placed to the bottom of the blasthole with the help of a tamping rod (Figure 10); for shorter boreholes were used single charges of 0.050 kg. For longer holes double charges were applied. A reliable inert stemming was made.

Excellent swelling fragmentation of treated concrete was performed after blasting with pyrolant charges (Figure 11).

4 CONCLUSIONS

Researches for application of waste SBP and DBP after utilisation of decommissioned ammunitions for obtaining of non-detonating explosive cartridges, suitable for dimension stone mining, as well as for blasting activities at challenging and complex conditions. The velocities of propagation of the reaction of chemical destruction of tested 3 different high-energetic compositions were between 202 and 747 m/s depending on the diameter of the charges and ingredients.

Propellant-based samples do not show any tendency for transition from combustion to detonation in case of ignition with soft burning electric fuse-head.

Pyrolant Mixture #1 shows higher velocities of deflagration and in bigger diameters of the charges is inclined to pass from combustion to detonation, which makes it useful mainly for decoupled charges, mini-pyro-boosters or multi-deck charges from chained petards with small diameter, separated with air gaps.

In case of splitting with multiple blast-holes in a row, for achieving more smooth and equable cracks in necessary cut-planes, the spacing and collateral between drill-holes should be précised.

Despite the fact, that explosive is not detonating, a preloaded blasthole could cause some rupture damages or over-breaks around the charged area.

In-situ experiments for application of fast combusting pyrotechnic composition for blast-swelling of concrete in the volume of the mixer have shown satisfactory results – good fragmentation and absence of damages on the mixing barrel. There was no fumes emission, air-blast or fly-rocks after explosion of pyrolant composition.

5 ACKNOWLEDGEMENT

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Optimising blast hole loading with MWD and 3D image analysis

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ABSTRACT: In recent years, Smart Drills have enabled precise GPS hole navigation along with the generation of rich Measure While Drilling (MWD) data to provide a new perspective on subsurface conditions (Sandvik 2021). Over the same period, drones have enabled the collection of a visual, geometric, and hyperspectral geological data. Integrating these new data types into the blast design process allows blasters to optimise fragmentation and prevent flyrock by tailoring each segment of a blast hole to its specific conditions (Epiroc Rock Drills AB 2019). However, the application of these new technologies has not yet gained widespread adoption in day-to-day practices, largely due to the operational complexity introduced. To address this issue, this research sought to establish a new workflow for optimising hole loading using MWD and drone data that reduced operational complexity rather than increasing it. The objective was to identify a practical and robust process that could be incorporated into everyday operations rather than just special projects.

1 INTRODUCTION

The purpose of this research was to establish a new practical and robust process for incorporating Measure While Drilling (MWD) data into everyday blast design processes. In particular, the team focused on evaluating a method for identifying seams by combining MWD data from multiple holes with 3D contextual data. This research lays the groundwork for enabling custom hole loading by seam as well as AI-powered seam detection.

Firstly, this paper provides an interpretation framework for MWD data and an understanding of how MWD can be used to gain unique insight into rock mass properties. A list of common MWD parameters is presented with definitions.

Next, the paper outlines a real case study demonstrating a new workflow for using MWD data to identify different strata bands and apply this to make better loading decisions. Practical techniques are described for data capture, analysis, blast design, and blast performance measurement.

This represents a collaborative effort between the site leadership, the blasting contractor, the drilling OEM and the blasting software provider to create an efficient process for achieving measured improvements in blasting outcomes.

In closing, the paper discusses how these techniques can be applied to facilitate more streamlined implementation of variable energy loading. It also presents the future opportunities that machine learning will create for automating seam detection and charging design tailored to rock conditions.

2 MWD INTERPRETATION FRAMEWORK

Measure While Drilling (MWD) data refers to the sensor data collected from production drill rigs during operation (Schunnesson 1990). This is generally comprised of geospatial data (e.g.

Table 1. Most common data fields for MWD data.

Data field	Data type	Description
Hole depth	Geospatial (MWD)	The vector distance from the hole collar position to the current drill bit position measured in ft or m. Note: This is not just the elevation component
Penetration rate	Geospatial (MWD)	The velocity of the drill bit as it moves through the rock during drilling measured in ft/s or m/s.
Percussion pressure	Pressure (MWD)	The piston pressure used to power the hammer in Top Hammer or DTH drills
Feed pressure	Pressure (MWD)	The hydraulic pressure exerted on the drill stem to move the bit in the direction of drilling
Flush pressure	Pressure (MWD)	The compressed air pressure exerted to push the crushed rock from the drill hole up the outer annulus of the drill pipe and out of the hole
Rotation pressure	Pressure (MWD)	The hydraulic pressure applied to create torque on the drill stem and rotate it as it moves through the rock
Rock hardness	Calculation (MWD)	An estimate of the rock hardness calculated through a proprietary algorithm based on the other Data Types recorded. This may not have units.
Hole collar latitude, longitude and elevation	Geospatial (HNS)	Hole collar position determined by known GPS receiver location mounted on the drill and known displacement of the drill bit from the receiver based on control system information.
Hole toe latitude, longitude and elevation	Geospatial (HNS)	Hole toe position calculated from the known Azimuth and Inclination of the drill bit at the known Hole Collar Position.

penetration rate), pressure data (e.g. feed pressure) and calculation data (e.g. rock hardness) (Scoble Peck & Hendricks 1989). It is logged at regular intervals (~every 1" or 2 cm) down the hole as the drill operates (Epiroc Rock Drills AB 2019). Additionally, MWD-enabled drills are also often equipped with a Hole Navigation System (HNS) which captures GPS information on the hole collar position and projected path (Sandvik 2021).

A summary of the most common output data fields can be found in Table 1.

This machine information is collected by a range of different hardware devices and control systems; however, the output structure and format are relatively standardised across all providers (Mining Editor 2021). The main options for collecting MWD data are listed below.

OEM MWD
- Most new drills from major OEMs come equipped with the sensors to capture MWD data. Activating the data collection from these sensors require be an additional service.

OEM HNS
- Most major OEMs partner with GPS system providers to offer the option for an integrated HNS offering out of the box. Synchronising this system with site survey control can require an additional service.

After-market MWD
- Older drills can be retrofitted with MWD sensors by dedicated service and hardware providers

After-market HNS
- Most drills can be retrofitted with a HNS by the major GPS system providers

3 METHODOLOGY

Our research methodology followed six main steps, detailed herein.

3.1 3D photogrammetric data collection

The equipment used comprised of:

- Off-the-shelf drone with internal RTK GPS system (RTK not used for this project).
- GPS Rover connected with mine survey control system.

First, a series of five Ground Control Points were marked out on the bench surface and floor

Figure 1. Drone photo locations and ground control points.

below. These points were surveyed with the GPS Rover to provide reference points for the 3D model photogrammetry process.

Next, the drone was flown over the bench to collect a set of 57 overlapping images to be used to generate the 3D survey model. These comprised of two flight modes: an autopilot flight mission taking seven passes of nadir photos of the bench surface and floor; and a manual flight mission taking two passes of oblique photos looking at the bench face. Figure 1 shows the locations of each photo taken (white circles) and Ground Control Points (crosses).

3.2 3D photogrammetric processing and drilling design

The images and Ground Control Point data were uploaded to a cloud-based photogrammetry and blast design platform to generate a survey grade 3D photo model of the bench.

The team then used this 3D photo model to design the drill pattern with the tools built into the same software platform. The team designed an 8 ft × 9 ft (2.4 m × 2.7 m) three row staggered pattern with 29 holes as shown in Figure 2. Front row hole locations were optimised by analysing 3D burdens.

The design was then exported directly from the cloud-based blast design platform in the OEM's IREDES file format. This was then uploaded wirelessly to the Smart Drill through the web portal provided for the OEM's communication service.

3.3 Measure while drilling data collection

The equipment used for capturing MWD data was a Smart Drill fitted out with OEM drill sensors and GPS Hole Navigation System (HNS). It was synchronised with the mine site survey control system to match the data used for the 3D model Ground Control Points.

The holes were drilled using the HNS system to ensure accurate placement on the bench. As drilled HNS hole locations were compared with the design locations in the blast design platform to ensure drilling quality control.

The MWD data fields captured were Time Tag, Depth Tag, Antijamming State, Feed Pressure, Flushing Pressure, Penetration Rate, Percussion Pressure, Rock Detect, Rotation Pressure, Rotation Speed, Stabilator Pressure, Flushing Flow State, Engine rev/min, Automatic Drilling, Flushing

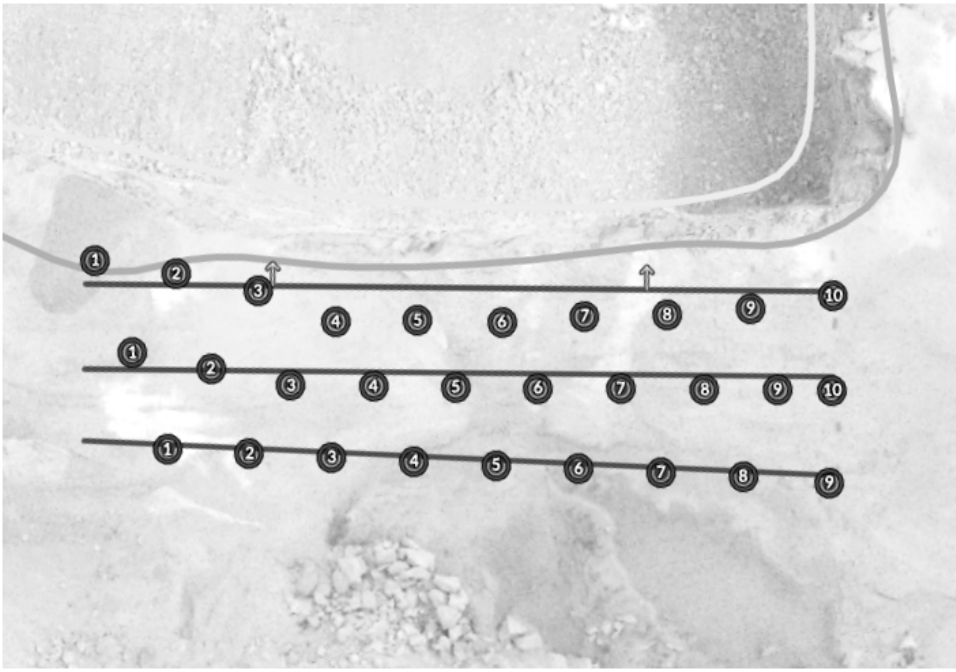
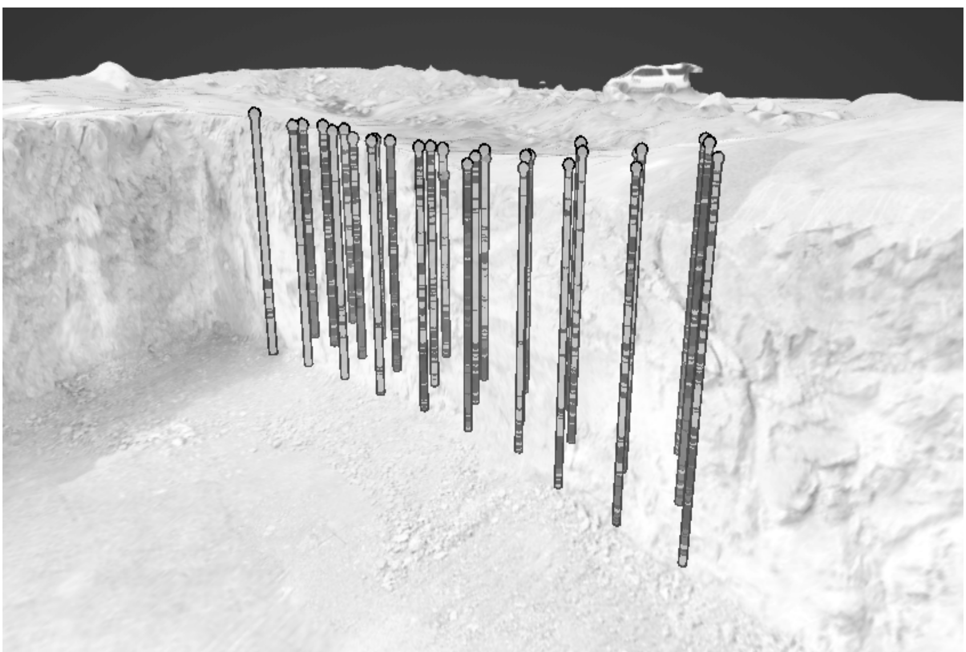


Figure 2. Drill pattern layout.


Figures 3. MWD data (penetration rate) in context of 3D photo model.

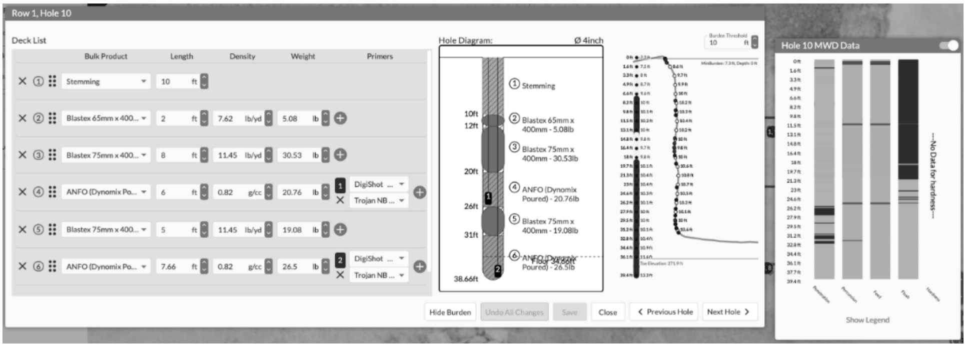


Figure 4. Blast loading design performed in context of 3D burdens and MWD data.

Level, Feed Level, Rock Contact Level, Tools Load Level.

3.4 *Measure while drilling seam analysis*

The MWD and HNS data were pulled wirelessly from the drill back into the cloud-based blast design platform for analysis.

The platform processed the MWD data and automatically combined it with the 3D photo model using the HNS information. Figure 3 shows the Penetration Rate extracted from MWD data visualised in the context of the 3D photo model.

Seam detection was also supported by quantitative analysis of the metrics at each depth interval. This was conducted using tools built into the blasting software which aggregate and analyse data from across all holes in the shot. Averages were taken across planes at each depth interval in the shot to identify trends in the bench geology.

3.5 *Contextual blast loading design*

The final step of the process was to integrate the MWD and 3D survey model insights into the blast loading design process.

This was achieved by visualising the MWD parameters as colour-coded bars beside the Burden Profile in the loading design module of the cloud-based blast design platform as shown in Figure 4. For each hole, the explosive products were adjusted based on the data collected.

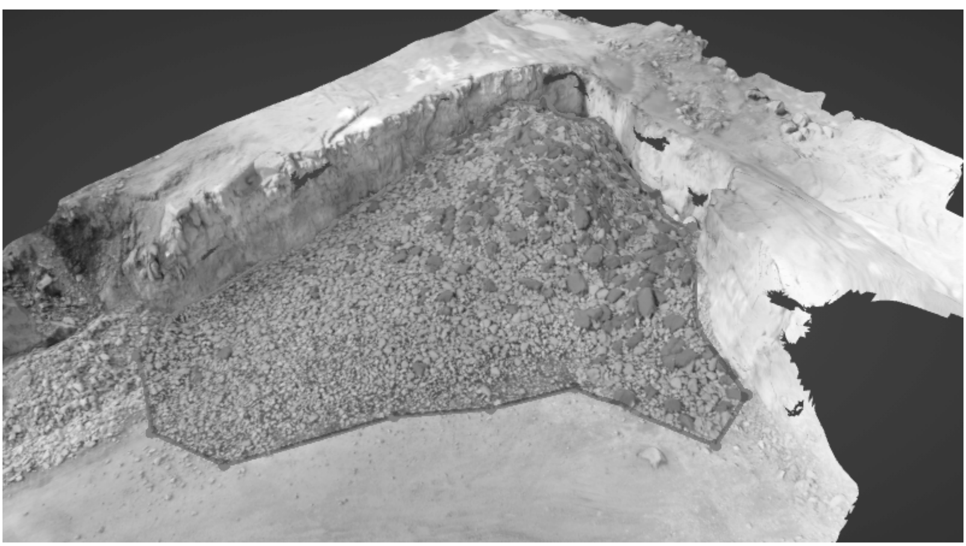


Figure 5. 3D photogrammetric model of muck pile with fragmentation analysis.

Table 2. Blast hole loading determined by burden and MWD analysis.

Hole 1	Poured ANFO to 31’ 3” Packaged Emulsion to 14’ 2.5” Packaged Emulsion to 10’, Stem
Hole 2	Poured ANFO to 28’ 3” Packaged Emulsion to 12’ 2.5” to 10’, Stem
Hole 3	Poured ANFO to 28’ 3” Packaged Emulsion to 12’ 2.5” to 10’, Stem
Hole 4	Poured ANFO to 10’, Stem
Hole 5	Poured ANFO to 25’ 3” Packaged Emulsion to 20’, poured ANFO to 15’ 3” Packaged Emulsion to 10’, Stem
Hole 6	Poured ANFO to 18’ 3” Packaged Emulsion to 10’, Stem
Hole 7	Poured ANFO to 16’ 3” Packaged Emulsion to 12’ 2.5” Packaged Emulsion to 10’, Stem
Hole 8	Poured ANFO to 10’, Stem
Hole 9	Poured ANFO to 28’ 3” Packaged Emulsion to 18’ 2.5” Packaged Emulsion to 10’, Stem
Hole 10	Poured ANFO to 31’ 3” Packaged Emulsion to 26’, Poured ANFO to 20’ 3” Packaged Emulsion to 12’ 2.5” Packaged Emulsion to 10’, Stem

3.6 Artificial intelligence post-blast analysis

After the blast was fired, the muck pile was immediately flown with the drone to capture post-blast images for blast performance analysis. These images were uploaded into the same cloud-based blast design platform to create a post-blast photogrammetric 3D model with automatically generated Fragmentation and Muck pile Movement analyses as shown in Figure 5.

In this case, Ground Control Points were not required, and the 3D model was created using the drone’s onboard GPS. To enable accurate Muck pile Movement analysis, the elevation of the post-blast model was calibrated to the pre-blast model using a common visible marker.

4 RESULTS

The seam analysis identified two distinct seams within the bench geology:

- A soft seam from 9.5–15 ft (2.9–4.6 m)
- A hard seam from 25–29.5 ft (7.6–9.0 m).

All front row holes were custom loaded based on burden and MWD data as shown in Table 2.

Tailoring the blast loading to the MWD data and 3D Burden data resulted in high quality blast outcomes. Fragmentation and Muck pile Movement analysis results are shown in Figures 6 and 7 as well as Table 3.

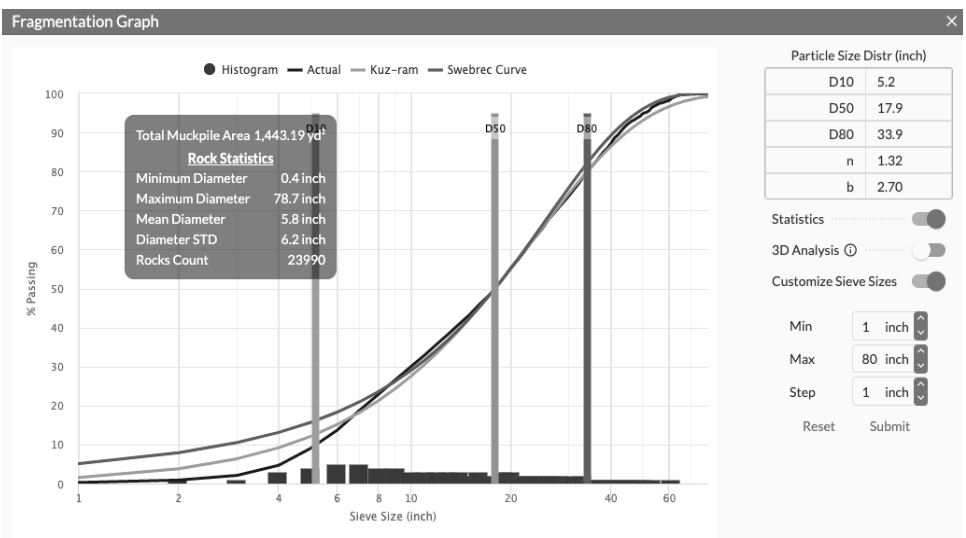


Figure 6. Results of automated fragmentation analysis.

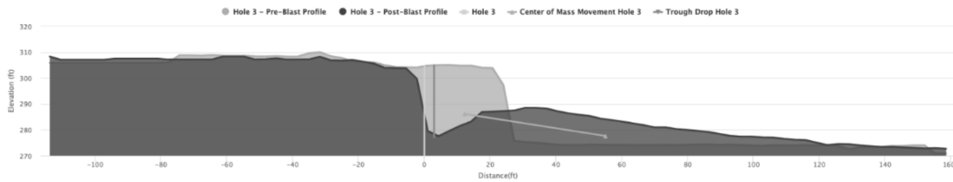


Figure 7. Example cross-section generated by automated muck pile movement analysis.

Table 3. Results of automated muck pile movement analysis.

Pre-blast volume	3782 yd^3
Post-blast volume	4749 yd^3
Swell factor	1.26
Average centre of mass movement	37.8 ft
Maximum throw	51.2 ft
Average throw	164.4 ft
Average trough drop	19.8 ft

5 ANALYSIS

The results indicate that incorporating MWD for seam identification and blast loading optimisation can be done in a practical way for everyday drilling and blasting operations.

This workflow produced improvements in blast outcomes and increased efficiency in drilling operations by eliminating the requirement to manually measure and lay out the holes.

During this research, the team identified that the usage of Post-Processed Kinematic (PPK) drones could further streamline the field operations by removing the need to mark out Ground Control Points.

The key enablers identified throughout the research process for implementing this approach were as follows:

- Strong collaboration between site teams, drilling contractors and blasting contractors.
- Focus on quality over speed while getting processes up and running.
- Minimising data touch points and automating processes where possible.

Interestingly, tailoring the blast loading with the visualisation of MWD and 3D burden data highlighted several situations where a loading decision made purely based on burden would not have been optimal. There were parts of holes where the minimum burden threshold should have been increased due to soft ground or voids and parts where it could be decreased because of hard ground.

This concept of a 'variable minimum burden' at different depths within a hole, based on rock properties and explosives options, has the potential to bring significant safety benefits to the blasting industry in preventing flyrock and should be further explored in future research.

The approach established in this research also represents a key enabler for more widespread use of differential energy loading. If variable density gassed emulsion product was available, the team could have designed the explosives column in decks of different densities side-by-side with the MWD output as in Figure 4. This could have allowed for a more streamlined charging operation in the field by avoiding the need to switch back and forth between Poured ANFO and packaged decks within each hole.

6 CONCLUSIONS

This research achieved its purpose of establishing a practical and robust method for applying MWD data to optimise blast hole loading in everyday operations. This lays the groundwork for a wide scope of future work optimising efficiency and safety of blasting operations.

New research should build on this by investigating the impact that a 'variable minimum burden' based on rock properties has on flyrock and front row fragmentation.

Additionally, future research should look to establish AI algorithms for automatic seam detection from MWD data. This could use a combination of pattern recognition and clustering methods to automate that process step.

All these steps lead toward a future where highly tailored and optimised blasting is accessible across more sites. Using technology to unlock new workflows that are practical as well as powerful will be the key to lifting the industry to the next level of safety and efficiency.

7 ACKNOWLEDGEMENTS

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Maastricht Conference Proceedings 2022, R. Holmberg et al

The art of detonation – energetic creation

P. Bosch
Member of the Dutch Association of Explosives Engineers

ABSTRACT: I am a visual artist from Belgium. Since the start of my practice, I have a great interest in working with energetic materials. In the beginning, this mainly resulted in art projects in which the visitors interacted with light and fire. Then I started to use pyrotechnics, and my activities evolved into happenings with explosions of paint/ice I initiate the transformation caused by energetic material and tried to visualise this in an aesthetic way. I use energetic material as an art medium to create sculptures, installations, performances and videos. Recently I realised there was still unexplored territory in the art landscape and wondered what was needed to get there. In order to be able to deal with high energetic material knowingly and skilfully, I took courses in working safely with explosive substances. I received my diplomas in performance art, pyrotechnics, firework, civil safety and blasting engineering. According to civil law, I operate as a blasting engineer and allowed to blast small objects such as rocks, tree stumps, bridges or structures up to 6 metres. Up until now, I have mainly been focused on discovering, defending and enabling the energetic material as art medium. My interest is the yet to be discovered creation possibilities of high-energy material. This research, the use of energetic materials as an art medium, is supported by the department of Arts and Culture.

1 IMPRESSIONS

1.1 Canvas

‘Canvas’ is an installation with a traditionally looking set-up of painting material that falls apart before the painter could start. This installation questions the use of the canvas and cherishes the moment when it comes to an end, and tries to show this in a way typical to the material. For this work (Figure 1) pyrotechnical electric squib was ignited with a 10 cap blasting machine.

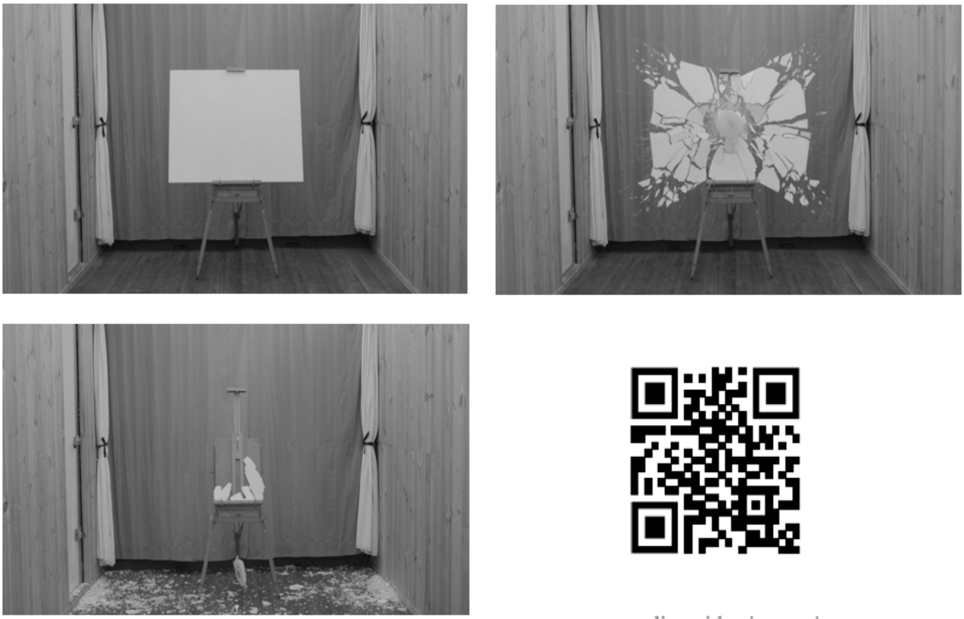
1.2 Ice experiments

‘Ice experiments’ is a video in which naturally red coloured ice blocks in different arrangements are being pulverised. The video shows a selection from a project in which the useless but beautiful fragmentation qualities of ice are displayed. For this work (Figure 2) pyrotechnical electric squibs were ignited with 9 v firing system.

1.3 Black powder

‘Black powder’ was a live performance, that allowed 100 protected participants to experience a controlled pyrotechnical deflagration of black powder fuse. These performances safely showed the almost surreal and typical properties of energetic material, and made it possible to experience them in a positive way.

For this work (Figure 3) pyrotechnical electric matches and 3000 metre rapid fuse based on black powder were used.

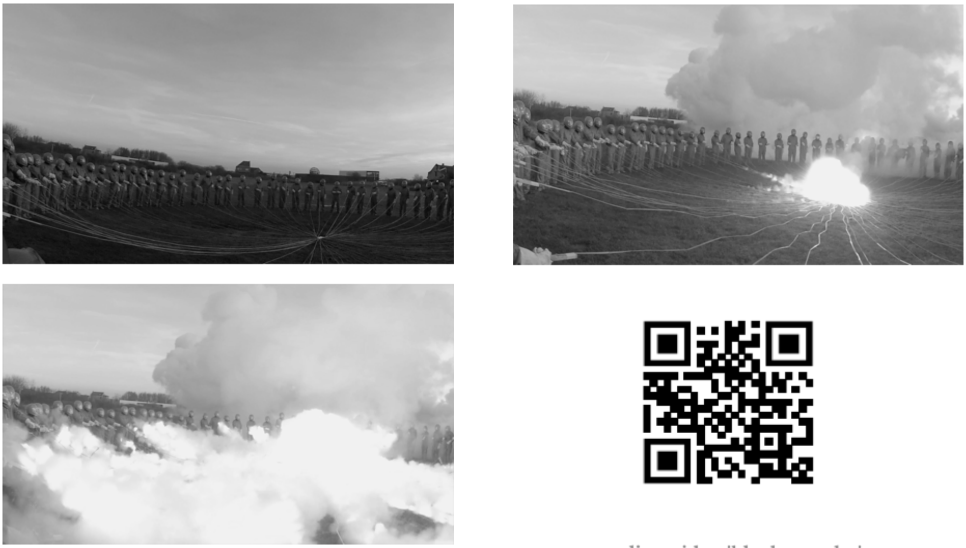


online video 'canvas'

Figure 1. See the ‘Canvas’ installation video by scanning the QR code.

online video 'ice experiments'

Figure 2. See the ‘Ice experiments’ installation video by scanning the QR code.



online video 'black powder'

Figure 3. See the ‘Black powder’ installation video by scanning the QR code.

2 ART OF DETONATION

2.1 Methodology

I am developing a series of 100 low tech experiments with high energetic materials as an art medium to examine the full range of the creation aspects. The application within the segment ‘art industry’ is a niche market, nevertheless I see enormous potential. The use of shock tubes, detonation cord, detonators and a range of different charges could be applied to regular art media like clay, stone, metal, paint and wood. Expanding the terminology associated with high energetic materials by for example study the work and life of Alfred Nobel as inventor of dynamite and the founder of the Nobel prize I consider as a part of this path to deal with the duality of high energetic material and the perception around it. Also more scientific, technical support could lead to a successful initiation of the segment ‘art of detonation’. Being already trained and allowed to work with it, brings me every time into state of being with servitude and hyper focus.

2.2 Laboratory

I have a mobile atelier to work with non-energetic material where needed and allowed.

I will further develop this into a ‘high energetic unit’ to actually perform these 100 experiments on site.

The places where I will actually be able to create this kind of work I have yet to discover and are probably military blasting sites, private test facilities or quarries. For all the experiments I will use a similar protocol that renders the phases visible: before, during and after initiation and impact on the surroundings. Related concepts associated with the use of this medium are; initiation, detonation, discharge, launch, gravity, perimeter, light, shockwave, speed, time and space. Illuminating the concept of explosives from ‘100 different angles’ and thus being able to expand the rather limited perception and connotation surrounding it, to high-energy moments. I would like to exhibit the experiments to a wider audience once they are finished.

2.3 Experiments

First test cases will be on view during this world conference at the booth with the red flag.

A series of further experiments that allow to visualise the concept of explosion with energetic material:

- examine imprint of the shape and impact of the explosion in different carriers in metal, wood, stone, soil
- make shock wave visible with the smallest possible amount of energetic material and regular medium
- use pressure wave of detonation or

Figure 4. Ideas for future experiments.

deflagration to test playing wind instruments such as flute, trumpet

- initiate detonation and reveal the light, sound and pressure waves with their velocities up to 8000 m/second
- develop ascent/launch principles starting with spatial figures such as sphere, cone, cylinder, beam, cube
- deconstructions based on gravity and everyday discarded objects based on their own construction
- further experiments as - explosion symphony, explosion garden, 1 kg variation, craters, inside a blast
- subjects from left to right/top to bottom: breach the door to success, last-ladder, 100 gr, blasting paint, cone.

3 CONCLUSIONS

The explosion itself is the ultimate form of creation and inspiration for me. I barely understand it but when I'm working on explosions it feels logical and makes sense. When an explosion occurs, time and space come together for me in a unique energetic way. The concept is inextricably linked to this medium that literally explodes into countless particles. The energy released, the discharge has something fundamental, a universe of options. The intangible is the reason why I want to make them visible, tangible and insightful. They are materials that, as it were, contain the life to which I can relate.

My aim is to develop the pilot project ‘the art of blasting’ in 2022.

Publication and exhibit the experiments; a methodology for work with a high energetic medium in the arts.

I hope to meet and will look for people during the conference who are interested in this niche segment.

For more information, questions, support or discussion, please contact info@pietervandenbosch.be or find me at the booth with the red flag. Have a blast.

Photo Yuni Mahieu

Website Pieter Van den Bosch

Figure 5. Pieter Van den Bosch.