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# Electrical Wire Explosions as a Basis for Alternative Blasting Techniques?

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## Abstract

Blasting companies have the need to replace conventional explosives by alternative blasting methods due to strong safety regulations for the transport and handling of conventional explosives. Investigations on exploding wires as an alternative blasting technique show possibilities for the economical application of this expensive technique. Principal investigations show the applicability of aluminium wires under water as a highly reactive substitute for conventional explosives. The investment costs for the required electrical energy supply can be reduced if, in a first step, the wires are heated slowly to the volatilisation temperature with subsequent electrically pulsed evaporation of the wire. A further reduction of the investment costs can be achieved using a modular electrical blasting system also applicable for other purposes during the preparation and the after-treatment of the blasting work itself.

## 1 Introduction

Severe disadvantages of chemical explosives are their extreme sensitivity against unintentional influences requiring special attention by educated personnel before, during, and even after the blasting process. Storage and transport underlie strong governmental regulations [1] obstructing the use of explosives for industrial purposes like explosive forming. Explosives must be secured against unauthorized persons. Improper handling of explosives is extremely dangerous. The regulations infringe upon a fast and uncomplicated use of explosives causing additional costs. Blasting companies show a principal interest in alternative blasting technologies (see fig. 1).

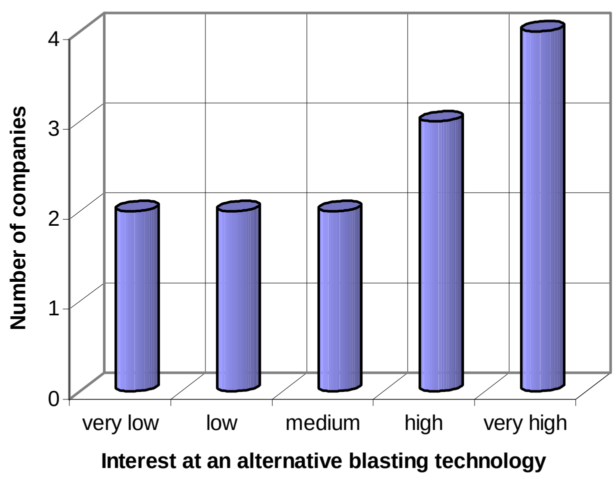


Fig. 1: Interest of companies for alternative blasting technologies.

In principle electrical wire explosions are suited as an alternative blasting technique. They are only dangerous during the explosion itself. Wire explosions were intensively investigated [2]. Only a small number of applications is established (e.g. [3,10]) due to high investment costs of the energy supply and its restricted mobility.

The paper presents technical approaches to reduce the investment costs by

- reduction of the electrical energy required for the blasting effect of a wire explosion
- reduction of the average power required to ignite the wire
- multiple use of the energy supply

First experiments show the principal feasibility of these considerations.

## 2 Reduction of electrical energy

Wire explosions consume energy for the heating, melting, overheating, and evaporating of the metal. E.g. aluminium requires 14 MJ/kg [2]. The blasting effect itself requires additional energy to pressurize the vaporized metal. A known possibility to avoid the need of additional energy is to initiate a chemical reaction between the aluminium and water [4]. Figure 2 shows the principal course of the pressure during the explosion of an aluminium wire under water: A first short pressure peak corresponds to the actual explosion of the wire whereas the second wide-spreaded pressure pulse correlates to the chemical reaction of the wire material with the surrounding water. The first pressure peak cracks the material to be blown up. The second pressure wave blows up the material.

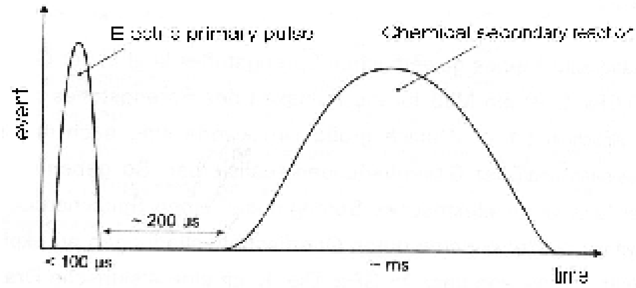


Fig. 2: Principal course of the pressure of an Al wire explosion under water [4].

Table 1 gives a comparison between a wire explosion with succeeding chemical Al+$H_2O$ reaction and a typical explosive like DONARIT®.

| Explosive | spec. energy 1) [MJ/kg] | spec. gas production 1) $m^3$/kg | spec. costs 2) [€/kg] | spec. costs of energy [€/MJ] | spec. costs of gas vol. [€/$m^3$] |
|---|---|---|---|---|---|
| DONARIT® | 4.1 | 0.900 | 18 (±50%) | 4.4 (±50%) | 20 (±50%) |
| Al+$H_2O$ | 7.5 | 0.632 | 5.11 | 0.68 | 8.09 |

Table 1: Comparison of DONARIT® and an Al/$H_2O$ explosive (Al evaporated).

The values marked with 1) are taken from [2]. The values marked with 2) are price estimates from 03/2001 where for aluminium respectively water the proportionate costs are 3.58 €/kg respectively 1.53 €/kg resulting in 2.56 €/kg of a stochiometric mixture of Al and water. Furthermore for Al+$H_2O$ a supplement of 100% is assumed for the capsule containing the material and for the energy required to evaporate the wire. The remaining values are deduced from these values. At same masses an Al+$H_2O$ reaction generates 180% of the energy generated by DONARIT® whereas the gas production is 70%. The specific costs for the production of energy respectively of gas using Al+$H_2O$ are (21±10)% respectively (54±27)% of the costs of chemical explosives.

From the point of consumption costs the use of Al+$H_2O$ explosives would be distinctly less expansive than the use of conventional explosives. The crucial point are high investment costs for the electrical energy supply needed.

To get an estimate of the costs of the energy supply a blasting operation at Lichtenau/Austria is considered [5]: 270 $m^3$ of rocks were blasted using 25 kg DONARIT®. The process of blasting was divided in 5 single blasting events. For each single blasting 5 kg explosives were used representing an energy of 20.5 MJ respectively a gas production of 4.5 $m^3$ at a price of 90 € (average price taken from data in table 1). This would correspond to an overall Al+$H_2O$ reaction mass of 2.72 (7.12) kg[a] with 1.36 (3.56) kg Al and 1.36 (3.56) kg water at costs of about 14 (37) € saving costs of about 76 (53) € compared to conventional explosives. To evaporate 1.36 (3.56) kg Al an energy of 19 (50) MJ is required.

Wire explosions are driven by capacitors. Cost estimates for capacitor facilities as function of the Al mass to be heated are shown in figure 3 based on the data given in table 2. The data are based on the assumption of optimum technical conditions, i.e. maximum 10% reversal voltage at the capacitors. Costs for prototyping are not taken into account.

| | basic costs | costs per unit |
|---|---|---|
| **generator unit** (diesel+el.gen.) | --- | 2.50k€/10 kW |
| **power supply** (~120 s charge) | --- | 14.80k€/10 kW |
| **capacitors (50 kJ/40 kV)** | --- | 3.50k€/cap. |
| **fuses** | --- | 1.30k€/cap. |
| **spark gaps** | --- | 15.00k€/2 MJ |
| **cables and armatures** | 3.00 k€ | 1.00k€/1 MJ |
| **control unit and auxiliaries** | 35.00 k€ | 2.10k€/1 MJ |
| **trucks/containers** | --- | 60.00k€/5 MJ |
| **engineering** | 170.00 k€ | 20.00k€/1 MJ |
| **overhead** | 15.00 % | --- |
| **tax** | 16.00 % | --- |

Table 2: Estimated costs of components of capacitive energy supplies and other costs.

As shown in figure 3, curve “1-step, evaporation” (dashed line, left axis) the overall costs for facilities able to evaporize 1.4 (3.6) kg Al are 4.4 (10.9) million €. At 76 (53) € cost saving per blasting the costs for the facilities would amortize after 57,900 (205,700) blastings. If the facility would be in operation each working day for 10 blasting events per day it would amortize after 5790 (20,570) working days or after 26 (93) years.

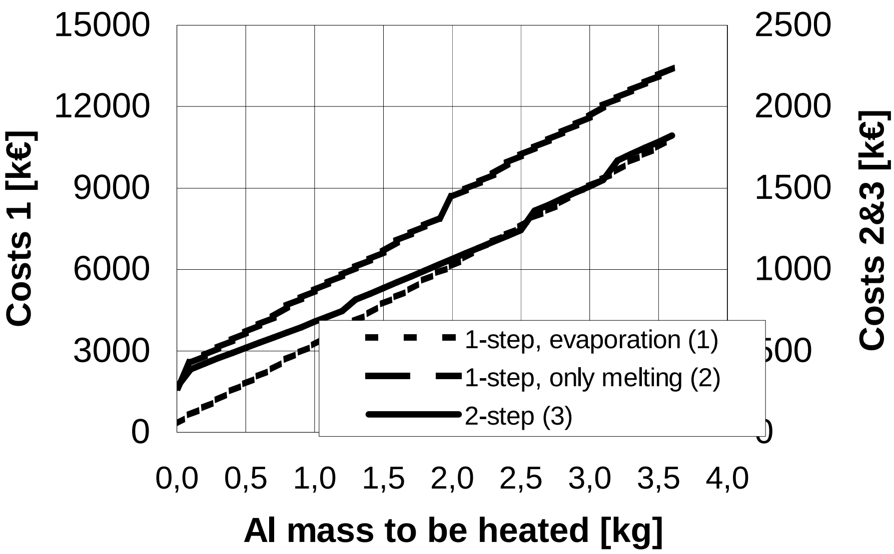


Fig. 3: Cost estimates of capacitive energy supplies as function of the aluminium mass to be heated
(1-step curve: left axis; other curves: right axes).

To replace conventional explosives by electrical blasting procedures considerable cost reductions are necessary.

## 3 Reduction of the average power

A cost reduction is possible reducing the power requirements restricting the heating to the liquefying and overheating of an aluminium wire until high currents force it by instabilities and magnetic forces to splash into and to react with the surrounding water. If no evaporation of the aluminium is needed and if the aluminium is heated-up to its evaporation temperature only 2.6 MJ/kg [2] instead of 14 MJ/kg are required. Applied to the example above the ca-

[a] Numbers outside parentheses relate to the energy production, number between parentheses relate to the gas production.

pacitive energy supply could be reduced to a 4-MJ (11-MJ) capacitor bank. As shown in figure 3, curve “1-step, only melting”, the investment costs would decrease to 1.1 (2.2) million €. This facility would amortize after 6 (19) years of continuous operation.

A further cost reduction is obtained if in a first step the wire is heated during 10 seconds with AC voltage from the generator unit until it is completely molten requiring 1 MJ per kg aluminium. In a second step a capacitor is discharged via the wire to overheat the liquid metal and to scatter it into the water. This overheating process needs 1.6 MJ per kg aluminium. The capacitive storage could be reduced to about 2 (5) MJ. As shown in figure 3, curve “2-step” the investment costs would be reduced to 0.85 (1.8) million €. This facility would amortize after 5 (15) years of continuous operation.

As shown the costs can be considerably reduced initiating the $Al+H_2O$ reaction by wire melting. Nevertheless the investment of an energy supply profitable not before 5 years restrains the introduction of an electrified blasting process for commercial purposes.

# 4 Multiple use of the energy supply and further advantages

A further return of invest ought to be possible, if the energy supply and its controls are used for multiple applications related to the blasting procedure:

- The energy supply has to be transported on trucks. Using the motors of the trucks to drive the generator, the generator unit could be reduced to the generator itself.
- Holes longer than 1 m must be drilled into the rock to fix the blasting capsules. The respective drilling machine(s) can be driven by the generator unit or, using electrical drilling methods [6], by the whole energy supply.
- After blasting the energy supply can be used to comminute large blocks of rocks caused by the blasting using by example a proven plasma blasting method described in [7,10].
- The energy supply can also be used to crack larger pieces of rocks into smaller pieces using arc generated shock waves under water or directly across the rocks [8,9]. If the rocks have metallic enclosures like gold they will also be liberated [8].

Other cost reducing advantages are:

- Simplified stock-keeping of all components. Unobserved illegal use is not possible due to the dimensions of the energy supply.
- Production, transportation and stock-keeping are not sanctioned by any governmental rules specific to explosives.
- In comparison to any other explosives the proposed $Al+H_2O$ explosives are safe even after an ignition failed and can be treated as non-explosives whereas conventional secure explosives are defined as explosives latest from the moment they are filled in the blasting hole. This essentially simplifies the removal of the faulty charge.
- Handling by persons not instructed in the handling of explosives is possible.

# 5 Principal experiments

The key task to reduce the costs of a aluminium-water based explosive is to reduce the need of energy. This could be realized with a 2-step heating of the aluminium wire.

## 5.1 Experimental Set-up

An aluminium wire is isolated alternatively with a silicone hose, with a spray varnish or plastic filler usually used to seal slits. The wire is fixed in a helical groove milled in the surface of a polyamide cylinder (diameter 35 mm; length 60 resp. 120 mm, depending on the length of the wire). The cylinder is placed in a cylindrical reaction chamber consisting of lead with an inner diameter of 150 mm, an outer diameter of 2500 mm, an inner height of 86 mm and a thickness of its bottom of 14 mm. The reaction chamber is filled with water.

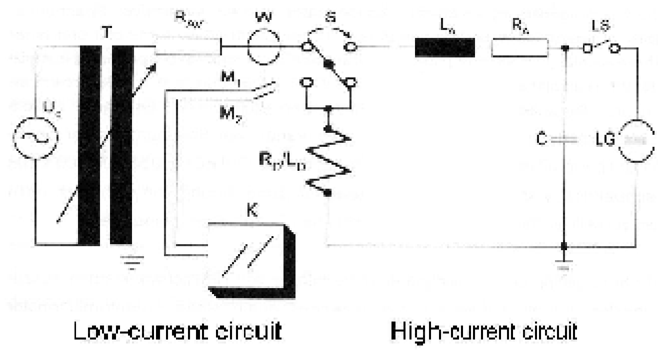


Fig. 4: Principal circuit diagram of the 2-stage power supply.

The wire is fed by a 2-stage power supply. The principal circuit diagram is shown in figure 4. The power supply consists of a low-current circuit for pre-heating of the wire and a high-current circuit for overheating the wire and scattering it into the water. The wire is marked with $R_D/L_D$. The circuits are switched to the wire via a pneumatic change-over switch *S* shown in its starting position when the wire is pre-heated from an adjustable transformer with a maximum secondary voltage of 400 V. The pre-heat circuit has a resistance of $R_{AV}$= 32 mΩ. The current in this circuit is measured with a current transformer *W* and is registered with a compensated curve tracer *K*. The high-current circuit consists of a 206-µF capacitor *C* to be charged by a power supply *LG* via a switch *LS*. After switch *LS* is opened and switch *S* has opened the low-current circuit and has closed the high-current circuit capacitor *C* is discharged via the high-current circuit inductivity $L_A$=13.2 µH and the resistance $R_A$=45 mΩ. The capacitor voltage is measured with a capacitive voltage divider. The current is measured with a Rogowski probe.

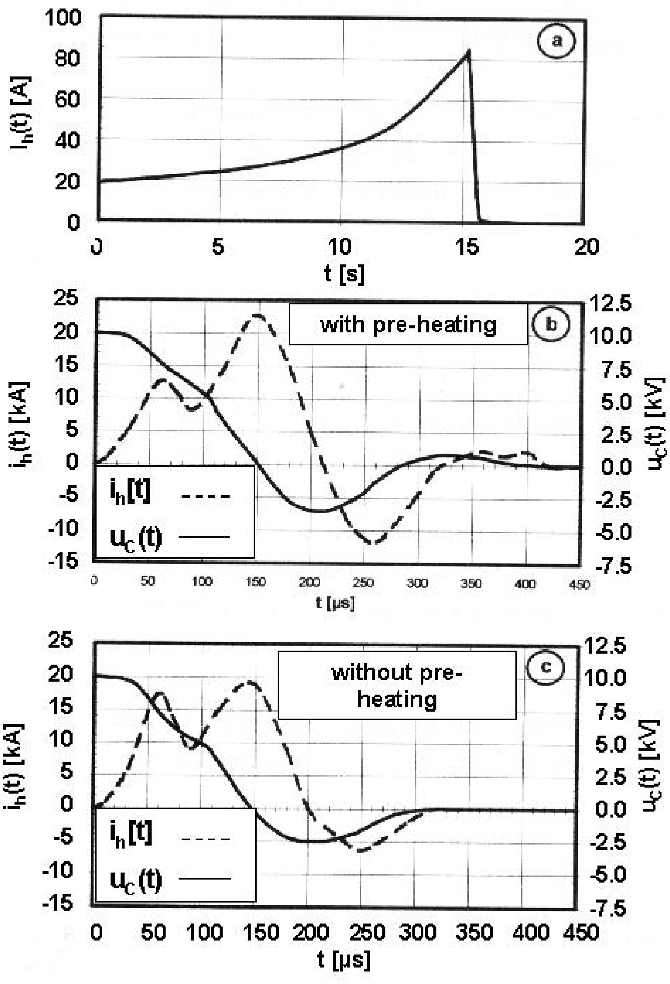


Fig. 5: Characteristic current and voltage wave forms.

## 5.2 Experimental results

Figure 5 shows characteristic current and voltage wave forms using an isolated 1-mm/2-m aluminium wire. The 400-V transformer was programmed in a way that the current increased during 15 seconds from 20 to 80 A (see fig. 4a). After switch-off of the low-current circuit and switch-on of the high-current circuit the capacitor discharged. Figure 4b shows the respective current and voltage wave forms. The current $i_h(t)$ (dashed line) has two maxima of 12.5 respectively of 22.5 kA. After 210 µs the current crosses zero. The following negative current amplitude is –12 kA. The voltage $u_C(t)$ (solid line) starts at the capacitor charging voltage of 10 kV and decreases in two steps in accordance to the current wave form to 0 V at t=150 µs. Like the current it is also slightly ringing. Figure 4c shows the current and voltage wave forms of an experiment when the wire was not pre-heated. The differences can clearly be seen. In both experiments no wire explosion occurred usually generating a typical voltage peak and a high mechanical pressure. However an explosion was realized: the lead cylinder was bulged.

Figure 6 shows results gained for a 1-mm/1-m wire at different conditions. The capacitor was charged to 10 kV respectively to 15 kV corresponding to $W_0$=10.3 kJ respectively 23.2 kJ. Furthermore the wire insulation as well as the heating method were varied. The best result was obtained if the wire was varnished, pre-heated, and the capacitive energy was 23.2 kJ (quadrant 2): the bulge of the bottom of the reaction chamber increased by 6 mm. At a capacitive energy of 10.3 kJ a smaller bulge of 4 mm was observed (quadrant 1). Changing the insulator to a plastic jacket or to a silicone hose lead to smaller (1 mm) or no bulges. Without pre-heating and at a capacitive energy of 10.3 kJ even a varnished wire didn't lead to a bulge of the lead cylinder.

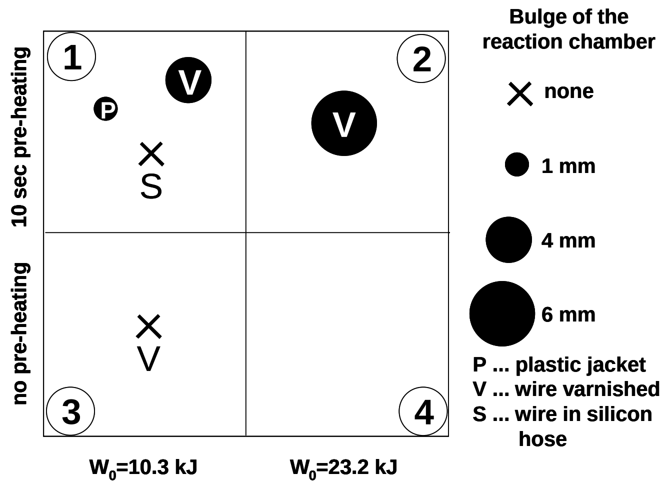

Fig. 6: Dependence of the bulge of the lead cylinder from different experimental situations.

## 5.3 Interpretation

The results show:

- A 2-step heating of the wire is possible
- The development of pressure is due to a chemical reaction between the aluminium wire and the water (no temporary abrupt current decrease; no or only poor effect if the wire is isolated with elastic materials like the plastic jacket or the silicon hose hindering an immediate contact between the aluminium and the water).
- The generation of pressure depends strongly on the type of the wire isolation.

# 6 Conclusion and outlook

Companies dealing with blasting services demand for alternative blasting techniques due to strong governmental restrictions considering the handling of explosives.

Wire explosions as an alternative for conventional explosives could be competitive if they are accompanied by a chemical reaction. To reduce the electrical energy required to bring the wire material like aluminium in reaction with an oxidizing material like water a 2-step heating of the wire reducing the costs for an adequate electrical energy supply by a factor of about 8 (see figure 3) is proposed.

In a first step the wire is pre-heated to the melting point with a low-power supply. In a second step the wire is overheated by a capacitive high-power supply. The wire has to be isolated if a liquid oxidizer like water is used. The isolating material has an essential influence on the blasting effect of the wire-oxidizer reaction.

A further reduction of costs could be accomplished if the electrical energy supply can be used for other applications during the preparation and after the blasting procedure.

Remaining questions to be investigated are:

- which influence do the multiple-use applications of the energy supply have on the costs of investment
- are there further multiple-use applications
- how a practical aluminium-water explosive looks like
- what is the minimum capacitive energy needed for the overheating process
- are there better possibilities to isolate the wire

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