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Paper

PARAMETER OPTIMIZATION IN MUNITIONS CUTTING USING ABRASIVE WATERJETS

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ABSTRACT

Conventional Abrasive Waterjet (AWJ) cutting systems have been used in the separation of 40 mm munitions components for recycling. A dedicated system has been built in the High Pressure Waterjet Laboratory (HPWL) of the Rock Mechanics and Explosives Research Center (RMERC), of the University of Missouri-Rolla (UMR) (which will become Missouri University of Science and Technology [Mo S & T] in December, 2007). The original design for the equipment had incorporated a set of operational parameter values, based on experiments carried out to optimize cutting of the 40-mm round. The application is now being extended to re-design the equipment for use in the separation of 60-mm munitions. This requires that a new set of optimized process parameters be established for best cutting of this larger round.

In this paper a factorial experiment was carried out in which the abrasive feed rate (AFR), rotational speed and jet pressure were varied as a means of determining the optimum cutting process. The initial metric for establishing the optimum cutting condition was of the time taken to cut through the round in an acceptable manner. However, while a reduced cutting time will be useful in integrating into the overall cycle time of the process, and in minimizing abrasive usage, the use of higher pressures and abrasive feeds may lead to a higher overall process cost, and so simplified costs are also calculated to determine the cost impact on optimization.

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1. INTRODUCTION

One of the unanticipated costs of the advances that are made in technology comes from the obsolescence that it creates in earlier devices. This is no different in the armed forces than it is in other aspects of conventional life. Thus, as new weapons are introduced to help the warfighter, so the older ammunition, which no longer works in the new equipment, becomes redundant. Storage of this equipment is costly, and where this stockpile of materiel also occupies space it makes it more difficult to store and access the new ammunition in a timely manner. Over the past year the inventory of stored, yet obsolete munitions, “the stockpile”, grew by over 43,000 tons, or some 6.2% of the earlier inventory, despite a steady effort to diminish the size.

Historically out-of-date ammunition was placed in carefully designed charges, which were then either burned out in open ranges, or detonated at designated sites [1]. This process, of Open Burn or Open Detonation (OB/OD) has come under increasing public scrutiny and concern. Not only can it give rise to unacceptable pollution of the environment, it also removes a potential resource from alternate use. Consider, for example, that explosive charges are needed to destroy landmines and other explosive devices that are found in areas of recent conflict (Bosnia, Cambodia, and Angola as examples). Many of the devices that are uncovered are booby trapped and unsafe to move, and must be destroyed, using a donor charge of explosive, where they are. Supplying that explosive from government stocks can be expensive and require considerable bureaucratic effort. An alternative is if some of the explosives in the devices being destroyed could be harvested [2]. A single 152 mm Russian OF540 round, for example, contains 6 kg of TNT that can be cut into 60 100-gm donor charges to be used locally in destroying landmines as they are found. In addition the scrap metal can then be sold to generate support income for the processing.

The ability to recover and reclaim these resources requires, however, an effective method for accessing and recovering the explosive from the munitions. In the case cited above, an Abrasive Slurry Waterjet (ASJ) was used in a simple linear cut across the munition. It took several passes of the nozzle to achieve total separation, with a total cutting time of 14 minutes, and the loss of 200 gm of the TNT. The unit also cost $85,000 and required a trained operator. In consequence the NGO working the system elected to change to the use of a remotely operated bandsaw.

In a situation where many tens of thousands of rounds must be processed to free-up needed space and reclaim the material in dealing with the United States stockpile, there are a number of reasons why the Cambodian answer will not work. Not least of these is that in one US installation where the bandsaw was used, they lost six saws to explosive reaction in a relatively short time interval. Abrasive waterjets can perform more effectively in this environment, particularly when married to robotic feed systems that provide automated feeds and controls, which ensure a safer working environment and effective recovery of all the resource.

The RMERC has been working with the Naval Surface Warfare Center, Crane Division (NSWC) and with El Dorado Engineering, and Ajax TOCCO to develop such a method for removing the explosive from smaller rounds, 40 and 60-mm, which contain significant quantities of explosive that can be reclaimed, as well as metal parts that can be recycled. As part of that process it is necessary to remove the fuse from the rounds, before the explosive itself is removed. Where the smaller round was to be sectioned, two cuts were needed, since the back-end of the round also contained a tracer element that contained energetic material [3]. With the need to minimize cutting time, it was found more effective to rotate the rounds, and to cut four rounds simultaneously. At a cutting pressure of 350 MPa it proved possible to section these rounds in as short a time as 12 seconds, with the limit on cutting time (a function of nozzle life) set at 35 seconds. As the nozzle wore during a week of operational use, the cutting time approached the upper limit, so that it proves cost effective to change-out the nozzles at the end of each week.

In this cutting mode, munitions cutting closely resembles the investigations of AWJ turning operations, which Hashish [4], [5] and Henning [6] have earlier described. This early work gives a better understanding to how the hydraulic and abrasive parameters affect the cutting results in a plane perpendicular to the axis of rotation of a workpiece. As the fixture (Figure 1) was redesigned for use in cutting 60-mm mortar rounds, it was found that only one cut would be needed to release the explosive. This simplified the construction of the cutting assembly, which had initially to hold eight cutting heads (Figure 2), and made maintenance simpler with the more open access to the simplified arm design (Figure 3). As before, the munitions have to be cut in a single plane perpendicular to the axis of symmetry. It was decided to achieve cutting with stationary jet and rotate the rounds, in order to make the cutting simpler, faster, and to better integrate into the automated operation of the facility. During this operation a robot will place the rounds in the fixture, the arm will swing into place, and the nozzles will be optimally located over the rounds. The water level is lifted to cover the rounds during cutting and a shroud on the arm seals the top of the unit to contain the abrasive and water. After the fuse ends have been cut through the free end drops, triggering a sensor which notifies the controller to stop rotation, abrasive feed and water supply. The cutting arm then swings out of the way, cleaning the rounds as it moves, and the robot returns to remove the cut parts, and insert a new set of rounds. Cycle time is anticipated to be around 1.5 minutes for a four-round set. To achieve that cycle it was necessary to optimize the AWJ cutting rate. In this case cut quality was not an over-riding issue.

The growth of industrial capability during the time of this program, meant that it is now possible to use a single 200-hp pump to supply the four cutting nozzles, and that cutting pressures of up to 420 MPa could be sustainably used in cutting. Thus the defining experiment examined the role of pressure, abrasive feed and rotational speed, on the cutting time needed to section the 60-mm projectiles. For this part of the experimentation unloaded rounds were used, and a number of adjacent cuts were made on the round bodies to limit the overall number of these required, since they are in short supply.

2. EXPERIMENTAL SETUP

A fixture was designed to hold and rotate the samples in the bed of the RMERC 5-axis cutting table (Figure 4). A standard abrasive head was used with a combination of diamond orifice and mixing tube with 0.254 mm and 0.762 mm diameters, respectively. The cutting operation was performed under water to contain splash and debris and the cutting head was fixed during the test (Figure 5). Representative tests were repeated in air, to compare the difference.

Commercially available 80 mesh abrasive garnet was used in this study. From [3] it was found that clockwise rotation relative to the cutting head position off dead-center is more effective than counter clockwise rotation. Based on those results the clockwise rotation was preferred. The rotational speed and abrasive feed rate were increased in a factorial experimental design.

3. PROCESS OPTIMIZATION –RESULTS AND DISCUSSION

The primary operation costs associated with the cutting operation in demilitarization include nozzle wear costs, abrasive costs and maintenance costs. As all of these costs increase with the time required to cut a single shell, thus cutting time was used to determine the efficiency of the change caused by a given set of parameters.

3.1 Influence of Abrasive Concentration on Cutting Process

Don Miller has given a persuasive argument [7] that abrasive concentration be used as the metric for the amount of abrasive used in cutting, rather than the absolute value of abrasive flow rate. By using the former it becomes easier to compare equivalent conditions across different jet pressures and nozzle diameters. This convention has therefore been adopted for this paper. It has the additional advantage, as well as being a dimensionless number that it is a better measure of the energy of the AWJ. The tests were conducted at 345 Mpa, 379 Mpa and 414 Mpa pressures. The rotational speed was varied from 10 rpm to 20 rpm in 2 rpm increments.

The results for 10 rpm through 20 rpm showed similar trends and the average cutting times for different pressures are plotted as a function of concentration in Figure 6. It should be noted that there is no change in the optimal concentration, when the pressure changes, (at 20% concentration). However this does mean that the abrasive feed rate should change with pressure to ensure the same concentration. These results tend to agree with those in [8], where a loading ratio term is used, which pegs optimal concentrations between 20 and 25%. This graph is a strong indicator towards the theory that abrasive concentration is much more effective index than the conventional Abrasive Feed Rate (AFR) used in AWJ cutting. In using abrasive concentrations as a measure it is possible to define a performance parameter that is constant across different ranges of pressures.

For the sake of comparison a few of the data points were repeated in air without the nozzle and shell submerged in water. The data is plotted in Figure 7 and confirm the existence of a similar optimum concentration in air.

3.2 Influence of Rotational speed on Cutting Process

An advantage of running the tests as a factorial, is that the effect of rotation speed can also be found. The summation values over different concentrations are plotted in Figure 8 and it is visible that for all three pressures the optimal rpm is at 18 rpm, although when the best-fit curves are run through the data it suggests that the rpm should be reduced slightly as pressure is increased.

3.3 Influence of Pressure and Concentration on relative abrasive costs

Using data from the factorial tests, relative abrasive costs was calculated using $1 a pound as a basis. The average costs for cutting at any given concentration over the range of rpms are plotted in Figure 9. The trends in comparative costs for the three pressures show abrasive usage cost is low at higher jet pressures, with the cost rising from that level when the lowest concentration was used. The curve does not consider the effects of enhanced nozzle wear on nozzle costs. That data is being acquired.

4. CONCLUSIONS

The important lessons learned from cutting 40mm shells have been extended to 60mm shell cutting. Higher pressures than those previously used in [4] have revealed that increasing the pressure does not change the optimal concentration for reduced cutting times. This is very important because in determining the optimal parameters for full scale operations the abrasive flow rate does not have to be experimentally determined again if any other pressure than the tested pressure is chosen.

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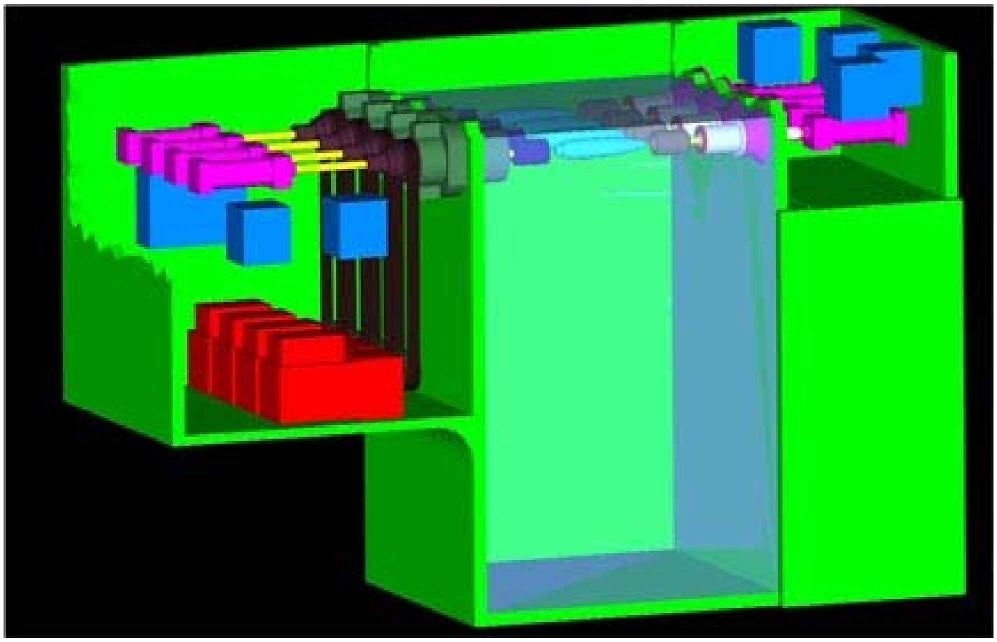

Figure 1: Original Fixture Design.

Figure 2: Original nozzle abrasive feed level on cutting table.

Figure 3: Simplified current cutting arm.

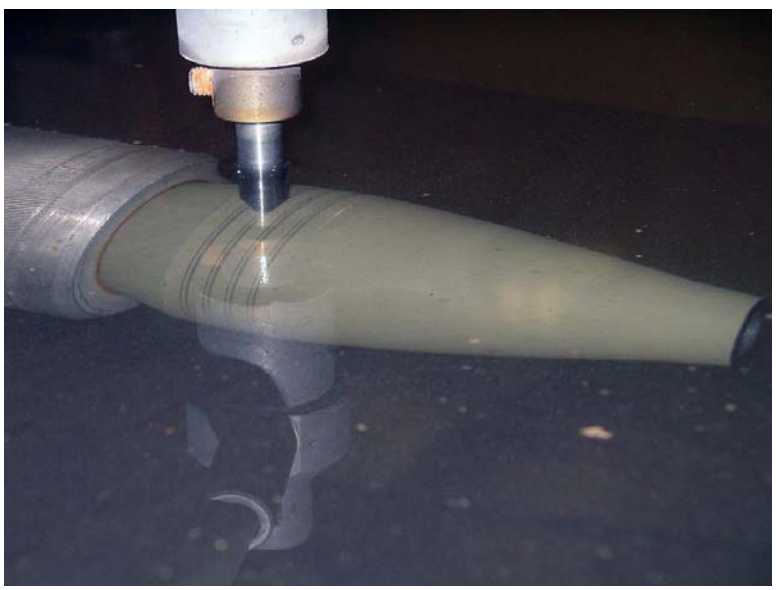

Figure 4: Shell holding and rotation fixture used for experiments underwater.

Figure 5: Real time cutting underwater.

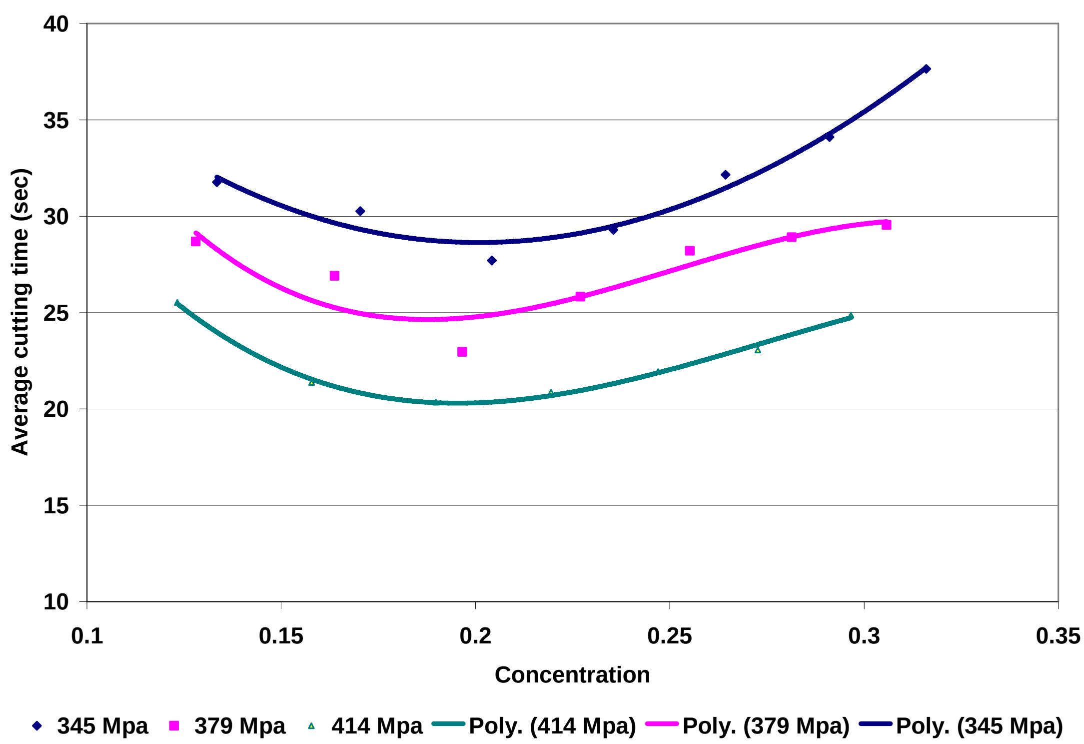

Figure 6: Effect of concentration in 60mm shell cutting times underwater.

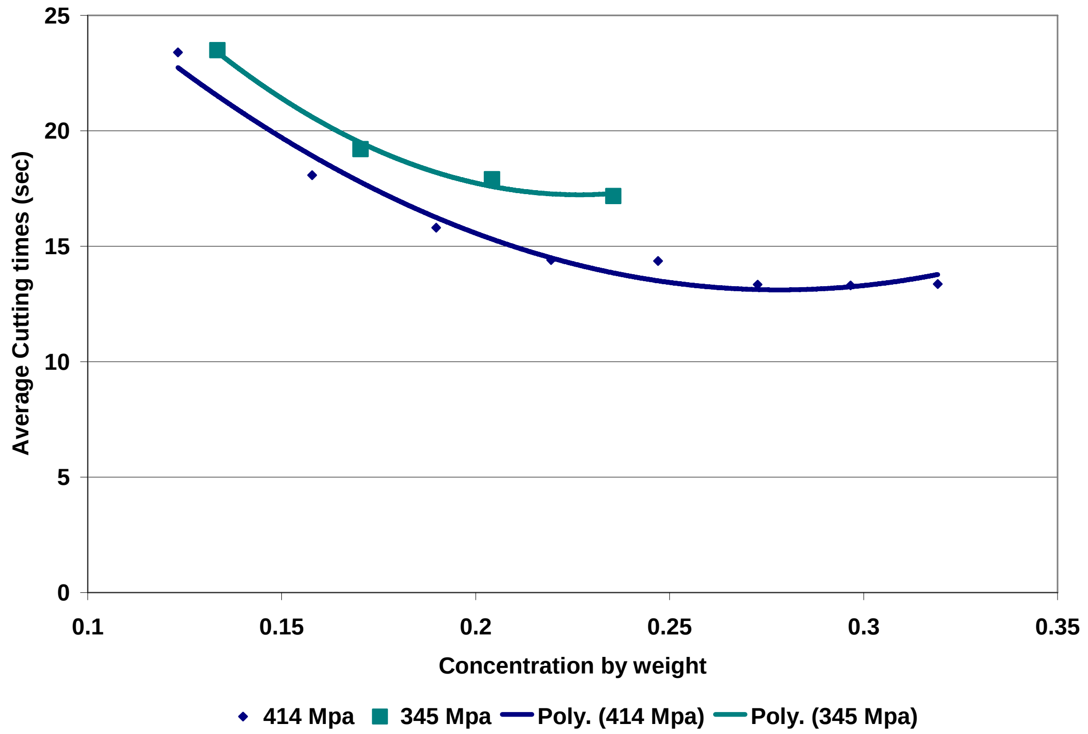

Figure 7: Effects of concentration on cutting times in air for different pressures.

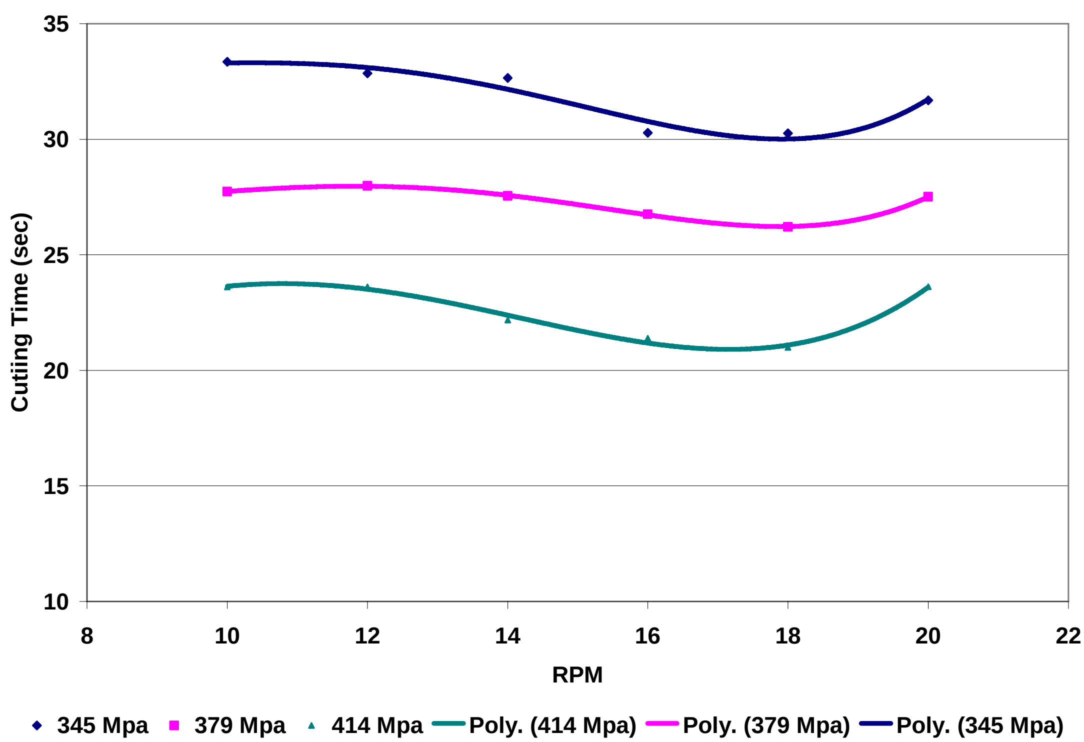

Figure 8: Effect of rotational speed on cutting times for different pressures.

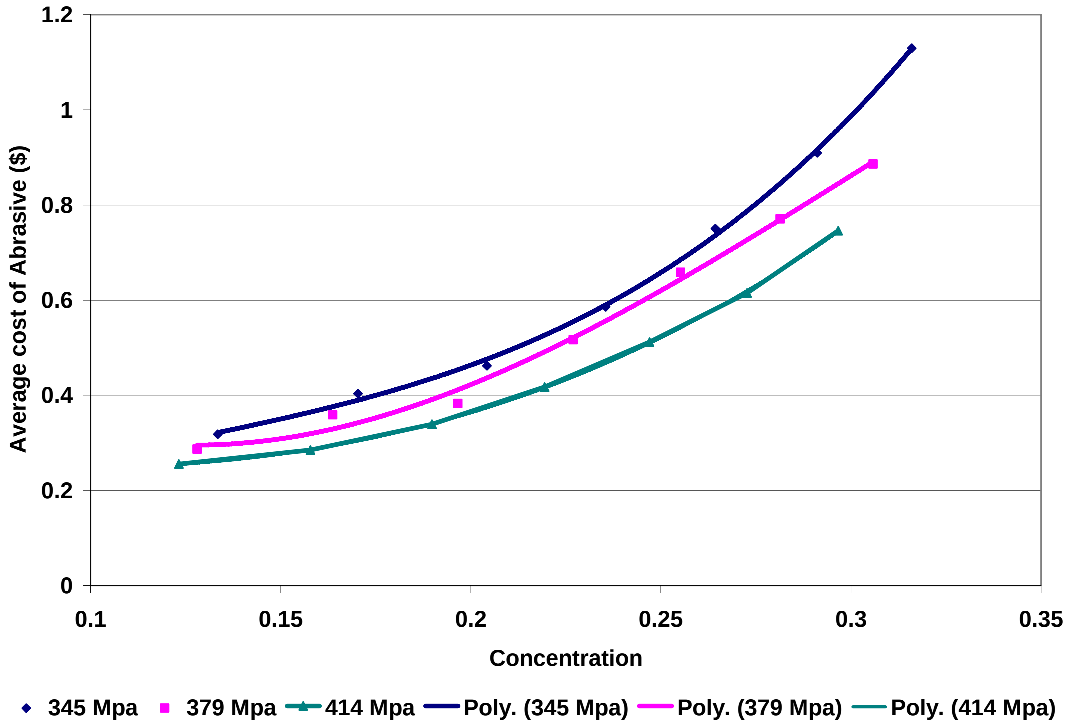

Figure 9: Effect of concentration on relative Abrasive costs for different pressures.