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# USING WATERJET IN REVERSE LOGISTIC OPERATIONS IN DISCARDED MUNITIONS PROCESSING

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Preliminary notes

This paper deals with presenting a manufacturing cutting process of munitions disposal by abrasive waterjet in order to increase safety of operator, environmental protection and material utilization. The paper aims at proposing an automatic line with abrasive waterjet cutting of unused munitions in order to utilize raw materials, increase safety and environment protection and exclude workers from the process. In order to find out and analyze the cutting process behaviour a non-thermal experimental cutting was performed of 100 mm antitank bullet Nk 100 ShK 44 TK by abrasive jet. Based on experimental results the structure of AWJ automated cutting system for discarded munitions was proposed. This unconventional technology can be easily implemented by this system. Increased effectiveness is also possible during munitions processing with the utilization of obtained metal scraps.

***Key words:*** *abrasive waterjet, anti tank bullet, automatic line*

## Uporaba vodenog mlaza u obrnutim logističkim operacijama kod obrade odbačenog streljiva

Prethodno priopćenje

Ovaj se rad bavi predstavljanjem proizvodnog procesa rezanja odloženog streljiva abrazivnim vodenim mlazom kako bi se povećala sigurnost operatera, zaštita okoliša i uporaba materijala. Cilj ovog članka je prijedlog automatske linije s rezanjem neiskorištenog streljiva abrazivnim vodenim mlazom kako bi se iskoristila sirovina, povećala sigurnost i zaštita okoliša te isključili radnici iz procesa. U cilju pronalaženja i analiziranja ponašanja procesa rezanja izveden je eksperiment ne-toplinskog eksperimentalnog rezanja protutenkovskih zrna od 100 mm, Nk 100 SHK 44 TK, pomoću abrazivnog mlaza. Na temelju eksperimentalnih rezultata predložena je struktura automatiziranog sustava za rezanje abrazivnim vodenim mlazom odbačenog streljiva. Ova se nekonvencionalna tehnologija lako može provesti pomoću ovog sustava uz moguće povećanje učinkovitosti tijekom obrade streljiva s iskorištenjem dobivenih metalnih komadića.

***Ključne riječi:*** *abrazivni vodeni mlaz, automatska linija, protutenkovski metak*

## 1 Introduction
Uvod

Throughout the world a lot of ammunition is stored which concentrate expensive material that is unused and unutilised. Ammunition significantly represents potential risk to human and their environment. According to analysis made by Kmeč [1, 2] it has been found, that discarded munitions are destroyed by using conventional techniques such as dumping at sea, outdoors burning and detonation, mining detonations and also open burning with combustion neutralisation [3, 4]. Destruction of discarded military munitions by conventional ways represents extremely hazardous process which is nowadays unacceptable. The procedure produces hazardous waste containing mainly Pb . In contrast there are non-traditional ways of discarded munitions processing with using a non-thermal way - the abrasive waterjet cutting (AWJ). The technology referred to as Abrasive Water Jet (AWJ) has been industrially used since 1983. The technological process uses the transformation of a high-pressure jet to a high-speed waterjet as a tool for materials cutting. By adding some fine abrasive (solid particles) better efficiency of cutting is achieved, thus expanding the possibilities of waterjet use [1, 7, 9]. The cooling effect of the AWJ process allows cutting some multicomponent materials in all directions, with simple shape cutting. The main advantages are: ability to cut some compound materials, use on soft and hard materials [10], no need for fixed workpiece, shape heterogeneity, no sparks by cutting, high accuracy, reliability and simplicity of operation, possibility of ending (starting) to cut on any spot, possibility of multilayer materials cutting. These advantages pose the AWJ technology where the emphasis is on improving the processes of ammunition demilitarization. This field of research is not covered and a lot of problems remain unsolved. Therefore, the aim of this paper is to design an automatic line with the use of that technology. The purpose is to improve the safety, excluding the workers to minimum and finally saving natural resources by using recycled materials obtained from destruction of discarded munitions by AWJ.

## 2 Related status
Prikaz stanja

When choosing a method of munitions disposal [15], we need to take into account some basic questions: what kind of munitions are expected to be destroyed, who will make it (armed forces, police, private security company), where it will take place (in a company facility, in a place outside of residential areas or in case the transferring of munitions means a big risk, on the place of its finding) how many of munitions need to be destroyed (one or a few thousand). Only after answering these questions can we find the best method of disposal whereby we must also take into account the cost and environmental consequences of any type of disposal [14]. Nowadays the ways of disposal can be divided into two basic types, the classic one and the new methods (Tab. 1). In terms of environmental impact and human health, the classic methods have a very disastrous impact i.e. heavy metal emissions (lead, antimony, barium), toxic gas emissions (HCl, $SO_2$, HCN), emission of highly resistant toxic substances (asbestos), and contamination of groundwater and soil [6, 12]. For the staff engaged in munitions disposal and also for the inhabitants of nearby cities it means an increased risk of carcinogenic diseases and heavy metal poisoning [8]. The conditions for selecting one of appropriate methods are described in Tab. 1.

Methods for processing of discarded munitions are used in a wide range of mechanical, electrical, thermal and chemical processes for material removal [15]. In addition to the "conventional" disposal technologies that have been responding to the need for machining of new materials e.g. using new cutting materials (cutting ceramics), the new technologies known as progressive (unconventional) technologies [4, 5, 11] also help with the problems of materials hard to be machined. Among the new ways of discarded munitions disposal are included: laser cutting, burning in plasma furnaces, cryofracturation, smelting, leaching, ammonia cutting, and hydroabrasive waterjet cutting [7, 9].

***Table 1*** *An overview of classical methods of discarded munitions disposal*
***Tablica 1.*** *Pregled klasičnih metoda odstranjivanja odbačenog streljiva*

| Technology | Technological conditions of application |
|---|---|
| Open detonation | There is no other technology available<br>Transport not possible<br>High security risks in the field of munitions disposal<br>Large and medium |
| Open burning | There is no other technology available<br>Limited quantity of munitions |
| Rotary furnace | A large number of small and medium munitions<br>After adjustment applicable to large calibrated munitions |
| Fluid combustion | A large amount of bulk explosives and fuel<br>Possible energy use |
| Hot gas decontamination | A large amount of contaminated waste metal |
| Detonation chambers | Limited quantity of munitions |
| Separation technologies | Recycling and reuse |
| Experimental conversion technologies | A specific application for hazardous materials as a prevention of highly toxic substances for environmental protection. |

Thermal methods are mostly used for disposal of munitions but it is also possible to use the liquid ones, either for cartridge leaching or for division of munitions. Water jet cutting of materials is a non – thermal method in which there is no heat added to the material. Using of appropriate medium (fluid) may be due to its chemical properties to achieve adequate results. Ammonia have shown suitable properties. Ammonia is a colourless irritating gas of room temperature. Nowadays it is one of the most produced chemicals with the volume of production of 90 million tons annually. Ammonia is used for cutting of M60 and M61 missiles that are like copies of the M55 chemical missilery, for the total elimination of chemical substances by alkali metals dissolved in ammonia gas and for cleaning the other parts of munitions due to their reuse or recycling [14, 12]. Great deal in the field was done by Miller, Summers, Fossey who belong to the pioneers among those using the high pressure AWJ as a viable alternative in that field. All reports show that the AWJ technology has a great potential because of no heat affected zone or change in the molecular structure occurs in the material. There is no distortion as seen with typical heat cutting methods. When cutting materials that are typically associated with hazardous fine airborne particles, these are removed and transported away from the surface into the tank by water, eliminating the risk and hazard.

## 3 Experimental cutting and discussion
## Eksperimentalno rezanje i rasprava

Machining test was conducted on the adjustable precise cutting table from PTV company, designed for application of the AWJ technology. Anti tank bullet of thickness 100 mm (projectile) and 130 mm (the case) was used for experimental testing. The workpiece was a machined tool generated by pump FLOW 9×D55 with $Q$ = 4,7 l/min with a power $P$ = 60 HP (81,6 kW) with an Ingersoll Rand cutting head. Detailed cutting conditions in the experiment are shown in Tab. 2.

***Table 2*** *Experimental cutting conditions*
***Tablica 2.*** *Eksperimentalni uvjeti rezanja*

| **Factors** | Level |
|---|---|
| Pressure $p$ / MPa | 350 |
| Traverse speed $v$ / mm/min | 15 |
| Abrasive mass flow rate $m_a$ / g/min | 300 |
| Water orifice diameter $d_o$ / mm | 0,33 |
| Focusing tube diameter $d_f$ / mm | 0,8 |
| Focusing tube length $l_f$ / mm | 72 |
| Standoff distance $z$ / mm | 3 |
| Number of passes | 1 |
| Angle of attack $\varphi$ / ° | 90° |
| Number of passes | axial direction |
| Abrasive | Barton Garnet |
| MESH | 80 |
| **Characteristic of intensifier** | PTV-37-60 PUMP |
| Type of intensifier [FLOW 9×D55] | double |
| Pressure in hydraulic circuit / MPa | 37 |
| Intensification ratio | 20 |
| Maximal pressure / MPa | 415 |
| Accumulator volume $V$ / l | 20 |
| Water mass flow | 3,68 l/min |

***Figure 1*** *100 mm artillery ammunition*
***Slika 1.*** *Artiljerijska municija 100 mm*

Munitions disposal by hydroabrasive jet is shown in Fig. 2. depicting the section of an artillery shrapnel shell. Fig. 3 shows a cross-section of the projectile created by abrasive waterjet. Experimental cutting was started at rim part of the casing used for loading with the traverse speed 15 mm/min. Experimental copy of antitank bullet signed as Nk 100 ShK 44 TK was without gunpowder and explosive charges. 100 ShK44 TK is indication of cannon inner diameter for bullet. Nk is the mark for cartridge with propellant. If we take into account continuous operation and net work time without the time needed for maintenance and service break we obtain 22,5 hours - 1350 minutes. From that time it is necessary to subtract the time for bullet handling. This time depends on the feed speed of the handling robot.

***Figure 2** Experimental cutting of anti tank bullet with AWJ*
***Slika 2.** Eksperimentalno rezanje protutenkovskog metka s abrazivnim vodenim mlazom*

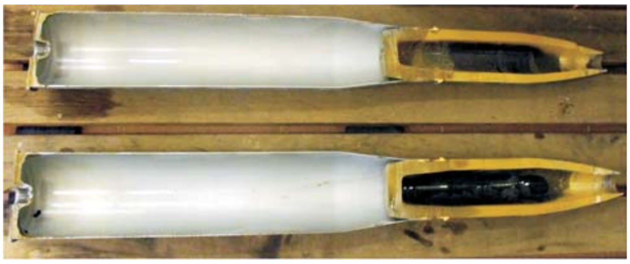

***Figure 3** Cut bullet with cartridge*
***Slika 3.** Presječen metak s čahurom*

To see whether the abrasive waterjet can cut the munitions we used a copy of 100 mm artillery anti-armour missile of total length 1000 mm with imitation of the primer, which ignites the propellant. A bullet with cartridge was cut on the machine which is commonly used in production. Traverse speed at the experimental cutting of bullet was 15 mm/min. Consumption of water, abrasive and total time per one bullet with cartridge is shown in Tab. 3.

***Table 3** Consumption of supply material and productivity*
***Tablica 3.** Potrošnja materijala i produktivnost*

| | |
|---|---|
| Traverse speed | 15 mm/min |
| Water consumption | 4 l/min |
| Abrasive consumption | 300 g/min |
| Total cutting time | 67,2 min |
| Daily consumption of water | 5400 l |
| Daily consumption of abrasive | 1620 kg |
| Daily production | 20 pieces |

This projectile was cut together with the cartridge. But if the bullet is to be cut separately from the primer, the rim part and the cartridge that is filled with gunpowder or cordite, productivity will be higher (Tab. 3). Cartridge can be emptied by turning it upside down, thus the cutting time will be significantly reduced and daily output will rise. This way of bullet processing was recommended by pyrotechnics mainly for security reasons. At hydroabrasive cutting of bullet (Fig. 2) there is no mixing of two different pyrotechnic composition (cartridges and bullets), whereas one is a powder charge and the other plastic. It is also necessary to cut the cartridge from which the match was removed and the dust content poured out. Possibility of daily production if we only cut the bullet of length 430 mm is shown in Tab. 4. It is shown that the number of bullets that can be disposed by AWJ increases by 133,5 %. But in that case it is necessary to include the time needed for transfer of the cut bullet and the time for handling the new bullet being cut.

***Table 4** Consumption of supply material and productivity*
***Tablica 4.** Potrošnja materijala i produktivnost*

| | |
|---|---|
| Traverse speed | 15 mm/min |
| Water consumption | 4 l/min |
| Total cutting time | 28,9 min |
| Daily consumption of water | 5400 l |
| Daily consumption of abrasive | 1620 kg |
| Daily production | 46 pieces |

## 4
## Proposal of workplace for munitions disposal with AWJ
### Prijedlog radnog mjesta za odstranjivanje streljiva abrazivnim vodenim mlazom

When designing the workplace for disposal of munitions, it is necessary to consider several important aspects: I - Safety for employees and environment, to avoid accidental firing; II - minimal number of personnel serving or their complete exclusion from processing the bullets; III - possibility of continuous operation (except the time needed for maintenance and cleaning)

For these reasons is the workplace divided in two independent workplaces. If we reduce workers to a minimum during bullet handling, three workers are sufficient for a regular operation, provided that the entire handling of ammunition is left to the robots. The only place where workers are needed is workplace number 1, where they unpack the containers of ammunition which is now ready to store on special pallets (Fig. 4). The other two workers will be retained as operators of proposed automatic lines, one for each department (Fig. 4).

The proposed concept has to be modular in order to ensure and enable flexibility of continuous improving. The quality of the system may be increased by a monitoring system based on vibration analysis or acoustic emission due to cutting of bullet problem parts [13, 20]. By using this method it is possible to ensure the technology efficiency of the material removal process. For successful realisation of full automation munitions processing with abrasive waterjet cutting technology is necessary to develop a new utilisation and devices. In order to ensure zero defect production system with on-line monitoring is needed, which is currently partially studied by [19, 20].

## 5
## Conclusion and remarks
### Zaključak i napomene

In the paper, a novel automated utilisation of experimental cutting of anti-tank bullet Nk 100 ShK 44 by abrasive waterjet cutting system presented (Fig. 4). Based on these results a structure for AWJ automated cutting system for discarded munitions has been proposed which will enable increasing effectiveness during munitions processing with utilisation of obtained metal scraps.

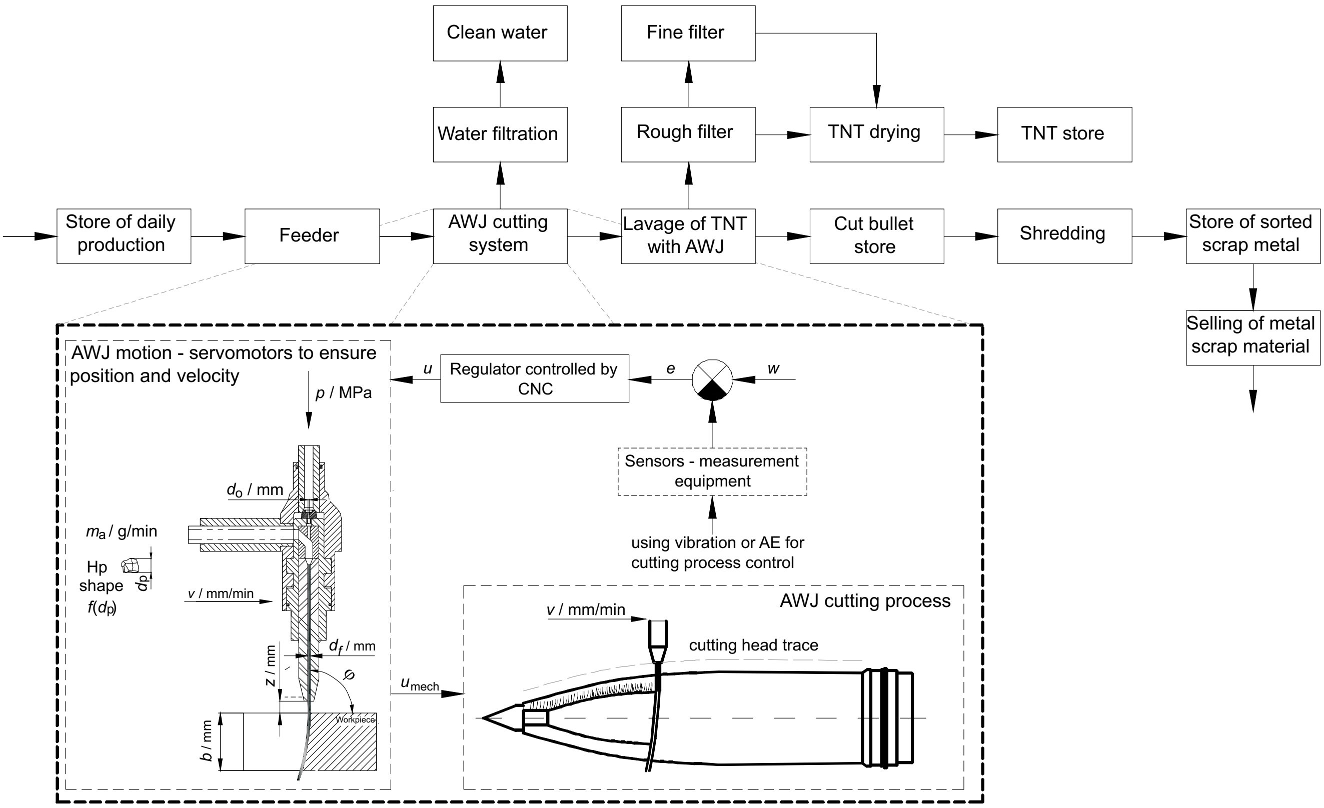


*__Figure 4__ Scheme of AWJ automated cutting system for discarded munitions, where: u - actuating quantity, w - required value, e - deviation, $u_{mech}$ - mechanical actuating quantity, z - standoff (mm), v - traverse speed (mm/min), $m_a$ - abrasive mass flow rate (g/min), p - pressure (MPa), $d_f$ - focusing tube diameter (mm), $d_o$ - orifice diameter (mm), b - bullet thickness (mm), φ - cutting angle (°)*

*__Slika 4__. Shema automatiziranog sustav za rezanje odbačenog streljiva abrazivnim vodenim mlazom, gdje je: u - pogonska količina, w - potrebna vrijednost, e - odstupanje, $u_{mech}$ - mehanička pogonska količina, z - zazor (mm), v – poprečna brzina (mm/min), $m_a$ - abrazivni maseni protok (g/min), p - tlak (MPa), $d_f$ - promjer cijevi sapnice (mm), $d_o$ - promjer grlića (mm), b – debljina metka (mm), φ - kut rezanja (°)*

Ongoing activities will deal with the implementation of diagnostic approaches. These tools are based in the form of a set of fuzzy rules [16, 17].

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## 6
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