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PROBLEMATYKA ZASTOSOWANIA PRODUKCJI PRZYROSTOWEJ W UTRZYMANIU SPRZĘTU WOJSKOWEGO

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THE PROBLEMS OF USING ADDITIVE MANUFACTURING IN MAINTENANCE OF MILITARY EQUIPMENT

Abstract:

Nowadays armed conflicts confirm the thesis about the necessity of military equipment maintaining in the shortest possible time and in the closest possible location. These activities are performed by the users of the equipment themselves or with the participation of mobile repair teams or service groups. The continuous development of technologies used in maintenance of military equipment, including additive manufacturing technology, increases the potential possibilities of their use in this process. The aim of the article is to identify key constraints, possible advantages and disadvantages of using AM technology in maintenance of military equipment. The research problem was specified as follows: does the current level of development of AM technology enable its rational use in maintenance of military equipment. The research was conducted using qualitative methods based on a review of selected literature from the last 10 years and the authors' own experience. the article concluded with several conclusions, one of which is as follows: the most commonly used materials in field maintaining of military equipment are polymers and composites.

Keywords*:* *additive manufacturing, military equipment, maintenance.*

INTRODUCTION

Additive manufacturing, which is increasingly used in military applications, offers a number of new possibilities related to quick and sometimes cheaper access to replaceable parts and consumables and tools. This becomes even faster in the context of having developed digital files that do not require any supplementation, ready for direct use in the additive manufacturing process.

Minimizing the time of military equipments renewal is a key task of combat service support. For this purpose, proven machining techniques (met-hods) are used, such as: welding, lathing, riveting, grinding, soldering, blacks-mithing, locksmithing and the latest technologies such as: gluing, computer-controlled machines (CNC) or 3D printing/additive manufacturing (AM). In the above activities, classic materials (metal and non-metal) and materials that are the peak of technological achievements are used.

However, new technologies, including additive manufacturing, constitute an extension of the possibilities of technical support and as such have already found their place in the armed forces of many countries [2, 3, 4, 8, 11]. However, new technologies have new requirements in terms of the possibilities of their use. The diversity of AM technologies [12] entails very large differences in the requirements of their work, and thus the possibilities of their use in different environments.

The authors of the article set themselves the goal of identifying the principle problems (advantages and disadvantages) of using AM technology in maintenance of military equipment.

The research problem was specified as follows: does the current level of development of AM technology enable its rational use in maintenance of military equipment? The research was conducted using qualitative methods based on a review of selected literature from the last 10 years and the authors' own experience. The article concludes with a thesis that the implementation of AM technology to perform maintenance of military equipment is rational, but with certain constrains.

1 MAINTENANCE of MILITARY EQUIPMENT

Maintenance of military egipment is performed in an exploitation fase in its cycle of life. The purpose of the exploitation phase is to maintain such organizational and technical conditions in the armed forces that the utility functions of the military equipment can be used at the assumed time, place and with a specified intensity and that the military equipment maintains its utility value. The exploitation phase of the military equipment consists of three stages [5]:

a) stage of implementation of military equipment to the armed forces – intended to implement the acquired new military equipment to the operational environment for the purpose of its further use in the Polish Armed Forces. SZ RP,
b) the stage of using the military equipment – intended for using the military equipment to perform specific tasks, in a specific operating environment, using its utility functions,
c) support – carried out alternately with the use stage, in order to provide organizational and technical conditions for using the utility functions of the military equipment.

Technical support (maintenance) is a deliberate action with efficient or inefficient/unfit military equipment, enabling its further use or storage. The purpose of technical support is to provide organizational and technical conditions for using the utility functions of military equipment and to ensure the appropriate level of its availability. Technical support is implemented in times of peace, crisis and war by all elements of the technical subsystem. It covers the needs of own troops and allied commitments.

Technical support in relation to land military equipment includes: technical reconnaissance, technical evacuation, technical maintenance (servicing), repair of military equipment, technical supply. The processes of technical support are illustrated graphically in Figure 1.

Figure 1 shows the classification of repairs in corrective repairs in relation to operations in war and crisis conditions. One of the main principles of military eqipment repairs, in this condition, is to perform them within a specified workload and available time. These mentioned factors are critical when considering the use of AM in military equipment repairs. Table 1 presents the characteristics of the classification of military equipment repairs carried out in the conditions of war and crisis.

In peace conditions, we distinguish repairs: current repair, medium repair, major repair, preservation repair, emergency repair, warranty repair, result repair.

The tasks of technical support of the Polish Armed Forces in times of peace, crisis and war are carried out in the following conditions:

a) field - mobile technical potential of the Polish Armed Forces, allied and coalition potential and, to a limited extent, the potential of the non-military subsystem,
b) stationary - stationary technical potential of the Polish Armed Forces, the potential of the non-military system and, as far as possible, the mobile technical potential of the Polish Armed Forces, using technical infrastructure (military and, in justified cases, also available civilian).

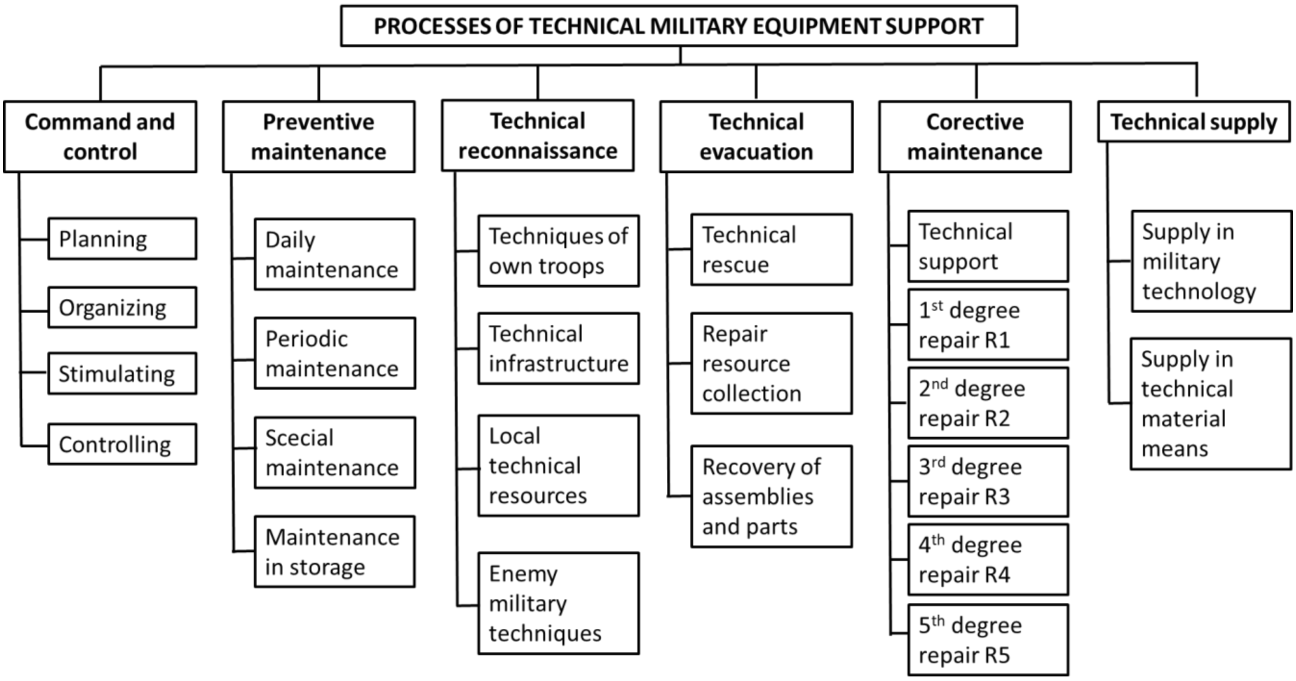

Figure 1 Military equipment technical support processes.
Source: own study K.Kowalski on the basis of: [5]

Moreover, the tasks of technical support of the Polish Armed Forces in times of peace, crisis and war are carried out in four levels of logistics support:

1. Level I – tactical (user level), up to and including the battalion, implemented by users and organic technical potential, for which subunit commanders are responsible.
2. Level II – tactical (workshop level), from the unit to the tactical formation inclusive, implemented with organic technical potential, services contracted by the Garrison Support Units and the dedicated technical potential of the organizational unit of the Ministry of National Defense responsible for the logistic support of the Polish Armed Forces, for which the commanders of units, tactical formations, commandants/commanders/chiefs of the Military Economic Units are responsible, respectively.
3. Level III – operational (intermediate level), implemented by the potential of the organizational unit of the Ministry of National Defense responsible for the logistic support of the Polish Armed Forces, bodies of military technical inspection, military metrology and military inspection of energy management, for which their chiefs/directors are responsible, respectively.
4. Level IV – strategic (enterprise level), is implemented using the strategic logistics resources of the national economy, including the economic defence links of the

non-military subsystem, the organisation of which, appropriate to its competence, is the responsibility of the P4 Logistics Directorate of the General Staff of the Polish Armed Forces.

One of the main principles of military equipment repair is to perform them within a specified workload and available time. In connection with this, field repairs are divided into: technical support, repairs no. R1, no. R2, no. R3, no. R4, no. R5. The features of military equipment repair are presented in Table 1.

Table 1. The features of military equipment repair in war and crisis conditions

Field repair	**Workload** [working hours]	**Lead Time** [hours]	**Executive**
Technical support	16	-	Repair platoon Battalion
Repair No 1	40	12	Repair company Brigade
Repair No 2	60	24	Repair battalion Division
Repair No 3	120	48	Repair battalion Logistics Brigade
Repair No 4	300	96	Technical workshops, Regional technical workshops from Regional logistics base
Repair No 5	4000	-	Military repair and production companies, production plants of the national economy

source: own work by K. Kowalski on the basis of: [7]

2 ADDITIVE MANUFACTURING TECHNOLOGY

Additive Manufacturing is definied as a printing of the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer tech-nology. In turn, the process itself AM is a mechanism of joining materials to make objects from 3D model data, usually layered. The idea of AM is based on the creation of three-dimensional objects using special printers [15]. AM technology is a „proces of joining materials to make parts from 3D model data usually layer by layer.”[1]

[1] ISO / ASTM52900-15, Standard Terminology for Additive Manufacturing – General Prin-ciples – Terminology, ASTM International, West Conshohocken, PA, 2015 http://www.astm.org/cgi-bin/resolver.cgi?ISOASTM52900.

ASTM International describes seven broad categories of AM that combine raw material and Energy in different ways, Figure 2.

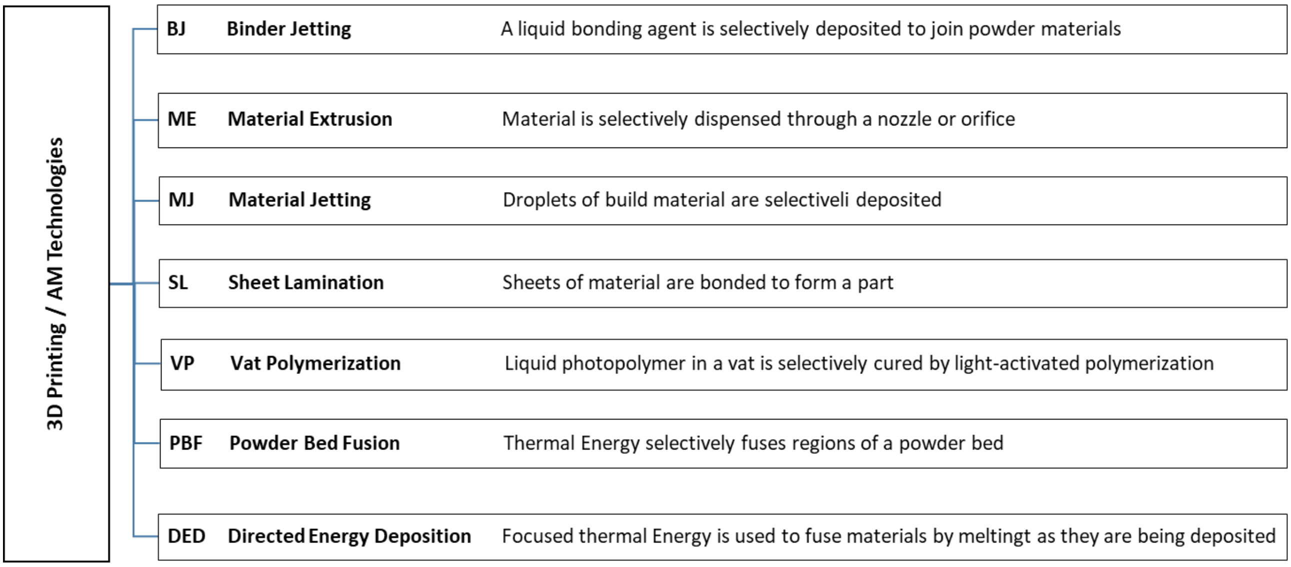

Figure 2. Industry recognized types of additive manufacturing processes
source: own work by K. Kowalski on the basis of: [6]

AM creates the part and material at the same time. This improves production speed and flexibility, but requires careful control of the AM process. AM can be used to: build parts that cannot be made any other way, uniquely combine materials, produce obsolete parts, rapidly prototype, create tools and specialized job aids. AM is a powerful tool to enable innovation and modernization of defense systems, support readiness and enhance warfighter readiness [6].

Additive printing manufacturing can be implemented using different materials. Most AM processes can only use certain types and forms of materials. Metals, polymers, ceramics, resins and composites are often used as raw materials in AM processes. AM printing raw materials also come in various forms, such as powder, sheet, liquid, and fiber. Among AM raw materials, thermoplastic polymers are the most commonly used material. Dedicated AM technologies for polymers are shown in Table 2.

Table 2. Breakdown structure of Additive Manufacturing for polymers (according to DIN EN ISO/ASTM terminology)

ADDITIVE MANUFACTURING FOR POLYMER	**PBF** Powder Bed Fusion	**MJF** *Multi Jet Fusion* Fused with agent + energy	Tiny liquid droplets are applied locally to a layer of polimer powder. They increase or suppress the heat absorption of the powder. An integrally acting infrared source melts the material - respectively
		SLS *Selective Laser Sintering* Fused with laser	By means of a movable laser beam, a polymer powder is selectively sintered locally layer by layer and thus solidifies a cross-section of the component
	MEX Material Extrusion	**FDM** *Fused Deposition Modeling* Material extrusion filament	Wire-shaped plastic, so-called filament, is plasticized in a nozzle unit and selectively dosed locally layer by layer
		APF *Arburg Plastic Freeforming* Material extrusion Granulate	Plastic granulate is plasticized in-a nozzle unit and selectively dosed locally layer by layer
	MJT Material Jetting	**MJT** *Material Jetting* Cured with UV light	Small droplets of photopolymer are applied locally and layer by layer through many nozzles. The-viscous photopolymer is then cured instantly by UV-light
	VPP Vat Photopoly merization	**SLA** *Stereo Lithography* Cured with laser	By means of a movable laser beam, a viscous photopolymer is selectively cured locally in layers and solidifi es there
		DLP Direct Light Processing	Cured with projector

source: own work by K. Kowalski on the basis of: [12]

AM technology is a multistep proces which in most cases cannot be bypassed or accelerated. In most publications, three basic stages are distinguished in the additive manufacturing process: preprocessing, manufacturing, postprocessing [1, 9, 10].

In each of the above mentioned stages, the problem formulated in the following questions should be solved.

For preprocessing:

1. What are the component and material properties that the AM component should have in any case?
2. Is the material generally or specifically qualified or validated for the intended application?
3. What is especially important for „Design for Additive Manufacturing”?
4. Are there special design specifications for the AM compliant component design?
5. What design possibilities result from AM compliant component design?
6. In which way must the CAD data of the part model be available?
7. Is a special AM process particularly suitable for the desired components?

For AM manufacturing:

1. Can the AM process be integrated into existing processes?
2. How much support is required for the desired AM process?
3. What maintenance costs are to be expected for the AM process?
4. Are the materials freely available for purchase or can they only be purchased originally from the system manufacturer?
5. Is the system a black box or can production parameters be individually adjusted?
6. Are there special protection requirements for people and the environment?
7. What is the production / building speed of the AM process?

For postprocessing:

1. Is there any special post-processing work on the AM components?
2. Do the AM components have to be after treated in a further process step?
3. Can material not used in the AM process be recycled?
4. How must the unused material be handled?
5. Does the component quality have to be proven by a qualification, e.g. by a non-destructive testing procedure?

Due to the wide spectrum of different technologies and materials used in additive manufacturing, and therefore the „ease” of their use in military equipment maintenance, in particular their susceptibility to repairs of military equipment should be specified.

3 ADDITIVE MANUFACTURING IN MILITARY EQUIPMENT MAINTENANCE

The potential for the use of AM in the Polish Armed Forces lies in the following areas:

- prototyping for rapid innovation and reverse engineering (Figure 3),
- repair of conventionally manufactured parts,
- production aids supporting conventional production,
- production of parts typically manufactured using conventional methods,
- production of new parts, components designed for AM and manufactured using AM,
- production of consumables and tools,
- use in medical support,
- production of material resources, e.g. ammunition.

Figure 3. From original part, through scan, print to replacement part
source: from the archives of K. Kowalski

The individual AM technology methods have their strengths and weaknesses in the context of their use in the armed forces. The detailed requirements and the importance of these requirements can be presented as follows:

– environmental requirements: exposure to high and low temperatures, humidity, sand and dust exposure, rain (including wind blown and freezing rain),
– technical requirements: what may be printed, print time, size of printed objects, quality of printed objects, intellectual property and legal considerations affecting the possibilities of using 3D printing,
– equipment & materials requirements: types and size of printers, types of materials used, appropriate power sources, specialized means of transport (boxes, containers, specialized bodies), 3D scanners, tools and post-processing devices,
– information requirements: 3D software and its development, resources for the database, exchange of information during crisis and combat operations, building common operational awareness in allied activities for land forces,
– placement & transportation requirements: adjustment to the method of operation of the repair system of land forces, the amount of AM funds at individual levels of the organizational structure, the method of transport of AM devices, additional measures ensuring the operation of devices in field conditions, e.g. power generators, UPS, etc.,
– supply chain resilience requirements: level of stocks, conditions in storage, means of transport, procedures, guaranteeing the availability of sources of supply,
– allied operations requirements: resource visibility, data and procedure compatibility, SOP, STANAG,
– woprkforce requirements: creation of new military specialties in army Logistics, access to and provision of training and development of personnel, creation of a training system in the land forces.

The above requirements and their importance imply the need to provide reliable answers to the following questions in the context of the use of AM technology at all levels of military equipment maintenance:

1. How to estimate (calculate) the value of AM equipment and materials for LF?
2. What should be the expected lifetime of AM equipment in LF?
3. How to model the life cycle and how to estimate the life cycle costs of AM in LF?
4. What should be the assumed minimum shelf life of AM materials?
5. In what weather and climatic conditions can AM equipment and materials can be used by the LF – temperatures, humidity, dust, etc.
6. How is it possible to ensure (meet expectations) the mobility of AM equipment and materials dedicated to LF – container, body?
7. How is it possible to ensure continuity and reliability of supply of AM equipment and materials in the country or during the expeditionary operations?
8. How is LF supposed to function reengineering and post-processing in field conditions?
9. How to organize information flows about the components made in 3D technology and AM material needs?
10. How to implement to the ordinary maintenance activity material flows and manufactured components and parts (supply chain) produced with using the AM?
11. How to organize information flows (information exchange) about parameters, patterns, component data and parts to be done in AM?

An attempt to answer some of the above questions is a temporary solution (Figure 4) presenting the expansion of the capabilities of a mobile universal containerized service and repair workshop by placing a scanner and 3D printers in it. In this way, the workshop can produce in reverse engineering (scanning, modeling, printing) polymer elements.

Figure 4. A mobile universal containerized service and repair workshop equipped with a scanner and 3D printers
source: from the archives of K. Kowalski

CONCLUSION

The following conclusions can be drawn from the analyses, research and own experiences conducted by the authors in the context of the problems of application of additive manufacturing in maintenance of military equipment:

1. The claim that 3D printing has the advantage of quickly repairing faulty parts is true in terms of manufacturing new parts and delivering them in an operational environment. In this aspect, 3D printing reduces the delivery time of parts that are not available on site. It can especially contribute to improving the supply of critical spare parts. But in field repair conditions, time pressure and environmental requirements only allow the production of components with reduced requirements.
2. The dynamic technological development of additive manufacturing and its technological diversity as well as the materials used imply the need for close cooperation between the state, the army and industry in order to optimally use 3D printing in the military environment.
3. Moreover, the cost of 3D printing technology still remains significant high, even though the average cost of 3D printers has decreased in recent years, the cost of materials and maintenance remains high. Additionally, you need to pay attention to the maintenance costs of 3D printers and the cost of materials. The rule here is - the more expensive the printer, the higher the maintenance costs and the more expensive the materials for its operation.
4. From the point of view of military technical support, it is worth considering outsourcing 3D printing needs or partnering with companies that offer on-demand printing services but this can work in stationary conditions.
5. Furthermore, dynamic technological progress in the field of 3D metal printing may soon lead to its wider use specially in field maintaining of military equipment, which will significantly contribute to shortening the waiting time for metal (or materials with the strength of metals) spare parts unavailable in the operational environment.
6. The analyses carried out show that the most commonly used materials in field maintaining of military equipment are polymers and composites.

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