Tools for protective equipment and Protection: Protective Equipment description and prospect

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Abstract

This paper concerns (1) the description (state-of-the-art) of protection equipment: individual protective equipment against blast and direct impacts (risks of demining tasks entrusted to human operators), platform protection (risks of highly shocks imposed to the wheels of mobile platforms, agricultural ones in particular), (2) the preliminary methodologies, techniques and results related to the intended protection tools

1. Introduction

It is essential that all demining activities must be performed with the highest available safety measures. Therefore it is important to lay down detailed procedures, descriptions and responsibilities that are to be followed methodically. This is called “active protection” and it is the most efficient solution for reducing substantially the probability of a demining accident and its consequences. Sadly, “active protection”, as efficient it can be, it is not sufficient. Even if all precautions are made, accidents will continue to happen. Thus the existence of a protective suit – “passive protection” might save lives. Current PPE are characterized by their heavy structure, their obtrusiveness of motion and their heat insulating effects. There have been reported cases of demining accidents in which the deminer had just removed (or partially removed) his visor due to overheat blurriness, only moments before the explosion [1]. Optimization of the laminated material that consists of the suit against perforation from fragments and critical overcompression of blast waves may contribute to a more lightweight and ergonomic design.

When demining operations are performed by using a vehicle to process the ground, it is assumed that such vehicle must satisfy some requirements. It is important, in fact, that in case of explosion the vehicle does not suffer relevant damage which might compromise its functioning. Since the vehicle touches the ground by its wheels, it is easy to understand that whether a blast occurs, the critical components of the vehicle are obviously the wheels. In the past, some solutions have been proposed in order to equip the vehicle with blast resistant wheels. The major contributions were provided by Vernon Joynt, who suggested to recur to high velocity of shock materials to design some components of the wheel. As it is known, the acoustic speed of a wave through a material depends on the Young modulus, the shear modulus and the density of the material: the stiffer the material (or the lower the density), the higher the velocity of propagation. Exploiting this physical concept, V. Joynt suggested to insert high velocity of shock components into the wheel, as shown in the figure below [2].

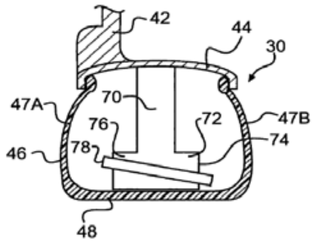

Fig. 1 - Diametrical section of the blast resistant wheel [2]

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The element 78 is made of high velocity of shock material which is employed to convert the energy of the blast in kinetic energy, protecting the vehicle from the shock. Such element is supposed to hit the sidewalls of the tire, which will be destroyed. Therefore, such a wheel is not able to retain its mechanical integrity. This requirement is satisfied by another design (also proposed by Joynt, [3]), shown in fig. 2.In such design, several high acoustic speed elements (16.2) are mounted on the rim, and they are separated from each other by layers of low acoustic speed material (16.3) with low friction coefficient.

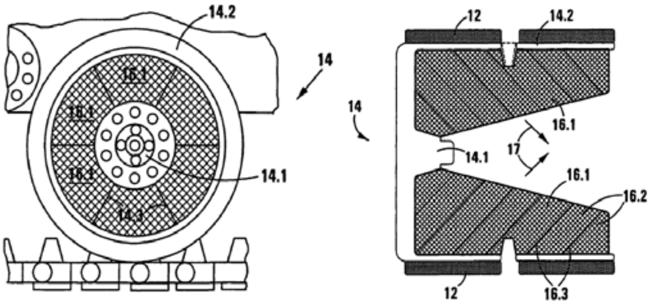

Fig. 2 - Front view (left) and diametrical section (right) of blast resistant wheel [3]

In the case presented in this paper, the vehicle used for the demining operations is a tractor, since the aim is to exploit the vehicle for agricultural activities after the mine clearance is achieved. From previous researches [4], the best solution seems to be the adoption of a blast resistant wheel composed of two parts: an outer part, made of steel, and an inner solid rubber tire embedded in it; such a wheel has already been used in Jordan but its general performances can be improved and the amount of energy transferred to the vehicle can be further reduced.

2. Personal protective equipment and methodologies

Currently, the development of PPE is based on two fundamental standards, STANAG 2920 [5] and IMAS 10.30 [6]. The first sets the limit for the protection against perforation from fragments using standard fragment simulating projectiles (FSP) and the second provides general guidelines on the circumstances of the blast tests. While the performance of the PPE against fragments is specified in detail, the desired response to blast loading hasn't been defined explicitly. That is because of the complex phenomena occurring during an explosion, the variations between the explosions of different mines and the absence of experimentally validated injury criteria against blasts using biofidelic models [7]. There are two known basic antipersonnel mine types that pose a threat to the deminer’s life, the blast mines and the fragmentation mines. The first are designed to severely injure the opponent through the destructive power of a blast wave and the second are made to eliminate the enemy by projecting an array of fragments. In reality, both types induce blast waves and project fragments [8]. Therefore it is desirable to develop PPE with the capacity of protecting against both mine lethal aspects. It is also desirable that the PPE would be lightweight, flexible with high water vapor permeability index and heat transmittance [9]. With the increment of thickness, the blast response of the PPE improves but at the same time the weight increases, the mobility hinders and the heat transmittance reduces up to a point, and then increases again as the heat transferring surface increases. The higher the number of layers of ballistic fabric, the risk of perforation from fragments is minimized but the blast response exacerbates [10]. Also, the fact that a fabric has high level of fragment impermeability that means that it will probably be impermeable to water vapor as well. Then, the only way to relieve the excess heat is by the pump effect, viz evaporate and convective heat transfer because of the forced air movement due to body movement and clothing looseness [11]. It is apparent that numerous tradeoffs are required in the design of PPE.

There are two material categories that are to be used in a PPE laminated structure. The soft or hard shell, usually made of ballistic fabric or fibre reinforced polymers and the core that can be a crushable material, granular, foam or honeycomb. The shell provides protection against the fragments and the core lengthens the duration of the blast's impulse, resulting in lower peak pressure.

Five steps of selection of materials will be conducted by the form of material characterization.

I. Crushable materials under impact loading using the Split Hopkinson Pressure Bar.

This will enable a quick selection of a number of different material options.

II. Crushable materials under blast loading.

This will verify the desirable response under blast. The amount of energy released will be according to the scaling laws of blast waves and will be proportional to the thickness of the crushable material.

III. Ballistic impact on soft fabrics and FRP

This will be conducted according to the NATO STANAG 2920.

IV. Ballistic impact and blast tests on combinations of materials selected in previous steps.

The coupling effect between the materials and the curvature effect of the laminate structure will be examined.

V. Hybrid Blast-Fragmentation tests

3. Blast resistant wheel

As learnt from previous researches, to provide the blast resistant wheel with an outer part made of steel is a good choice. The design of such part is intended to grant the continuity of the contact between the wheel and the ground, in order to make the driving comfortable also on hard ground, and, at the same time, to protect the inner part of the wheel in case of blast. The proposed design for this part of the wheel is shown in fig. 3.

Fig. 3 – Outer part of the wheel

Since the major requirement of this part is to retain its mechanical integrity whether a blast occurs, FEA simulations have been carried out to predict the damage suffered from the wheel; such simulations are intended to avoid unnecessary experimental tests, since they are expensive and time consuming.
The aim of the simulations is to evaluate the plastic deformation suffered by the steel part; in order to do this, mathematical model for plasticity and failure for the material taken into account must be provided. In this case, since the material is steel, a Johnson-Cook plasticity model and a Johnson-Cook failure model have been adopted [12]. The shockwave propagation has been modeled by recurring to shock EOS linear. To grant the reliability of the results, some preliminary simulations have been carried out on the outer part of another wheel, already tested in experimental tests; the results provided by the simulations matched those of the experiments, ensuring the validity of the setup. The simulation time has been set according to one of the empiric expressions to evaluate the duration of the positive phase of an explosion. The simulations show that the damage suffered from the outer part of the wheel is such that the wheel retains its mechanical integrity after the explosion of 240 g of TNT (as shown in fig. 4).
The inner part of the wheel may consist of a solid rubber tire embedded into the steel part. Other materials (e.g., compounds) can be exploited but the cost effectiveness must be taken into account.

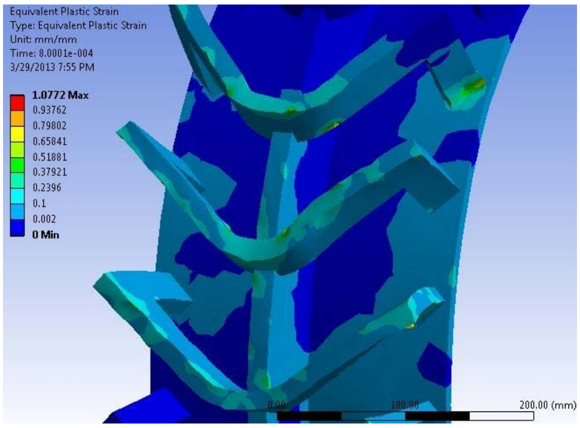

Fig. 4 – FEA simulation, plastic strain of the outer part of the wheel after a blast of 240 g of TNT (true scale)

4. Conclusions

The resulted laminated structure will be the suggested protective material for a deminer's suit and it will be able to protect the deminer from the blast effects and fragments from exploding mines.
The protection of the moving platform is achieved by recurring to blast resistant wheels, designed to retain their mechanical integrity and to reduce the amount of energy transferred to the vehicle. A wheel composed of a soft element protected by an outer steel part is designed to maintain its mechanical integrity, allowing to complete the demining operations before maintenance is strictly needed. Experimental tests will be performed to

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