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TECHNICAL NOTE

MRL-TN-503

TECHNIQUES FOR THE FIELD REPAIR OF ARMOUR BATTLE DAMAGE

N.M. Burman and C.G. Killoh

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Simple techniques for rapid repair of armour damaged in a battlefield are described. For aluminium armour of the type used on an armoured personnel carrier (APC) explosively driven fasteners are used, while for steel armours of the type used on tanks an adhesive bonding system is used. Both methods are shown to perform well in ballistic tests and in vehicle trials. Some limited testing of adhesive tape patching to prevent water ingress through small penetrations on an APC armour is also described.

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Techniques for the field repair of armour battle damage

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ABSTRACT

Simple techniques for rapid repair of armour damaged in a battlefield are described. For aluminium armour of the type used on an armoured personnel carrier (APC) explosively driven fasteners are used, while for steel armours of the type used on tanks an adhesive bonding system is used. Both methods are shown to perform well in ballistic tests and in vehicle trials. Some limited testing of adhesive tape patching to prevent water ingress through small penetrations on an APC armour is also described.

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TECHNIQUES FOR THE FIELD REPAIR OF ARMOUR BATTLE DAMAGE

1. INTRODUCTION

The logistic support philosophy for the repair and maintenance of the proposed Australian designed and built APC (Armoured Personnel Carrier) (Project Waler) stated that, 'Armoured vehicles, due to their importance and difficulties in backloading, are usually repaired as far forward as it practicable' [1]. Since such a requirement could be related to existing as well as proposed armoured vehicles, MRL conducted a small research program to develop APC patch repair techniques. The aims of the program were to develop a patching system which would:

(i) be simple to undertake with minimum specialised tools and equipment,

(ii) provide repair items, patches, fasteners and application tools, that would easily be carried as auxillary equipment in an APC and take up a minimum of space,

(iii) have short application time,

(iv) provide similar ballistic penetration resistance to the original armour,

(v) provide full air/water sealing (and thus probably NBC protection), and

(vi) not introduce any untoward corrosion problems.

Although there appeared to be no formal requirement for the forward repair of battle damaged Leopard Tank armour it was decided also to investigate the feasibility of repair for this vehicle using similar requirements to those outlined above for the APC.

Early attempts to use sheet plastic-explosive and serrated, steel mesh fasteners to attach aluminium repair patches to aluminium APC armour were unsuccessful. However, the use of hardened steel fastener pins, projected by an explosively loaded drive plate, proved a fast and effective method for repair patch application. The availability of proprietary, hardened steel fasteners, as used in the Ramset* system, suggested a suitable alternative patch application method.

Discussions with Army personnel indicated that in combat operations there was a common requirement to quickly repair perforations in APC hulls produced by armour piercing small-arms fire. In Vietnam for instance such perforations were plugged using readily available materials such as carved wooden plugs or pieces or cloth in order to waterproof the APC hull for fording. In a modern combat environment ingress of NBC agents as well as water may be a threat. Additionally in a situation where there was insufficient time to perform battle damage field repairs the availability of a technique for temporarily sealing perforations produced by small-arms and larger calibre projectiles would be advantageous. To this end MRL proposed a trial using a range of commercially available adhesive tapes as a means of rapid, temporary sealing of perforations.

2. LABORATORY EXPERIMENTS

2.1 M113 Armoured Personnel Carrier Patch Repair

Fastener penetration into M113 APC 5083 H321 aluminium alloy armour plate was tested using a range of Ramset fasteners and charge types, fired from a 6.35 mm (0.25") Ramset gun barrel. The two types of fastener used, a plain shank and a plain-threaded shank, Figure 1, were chosen to enable patches to be either permanently fixed or removable. The pull-out force required to extract these fasteners was measured on a tensile testing machine.

Using pre-drilled pilot holes in the patch and a purpose-designed locating jig, which allowed accurate positioning of the Ramset gun barrel end, 38 mm thick 5083 H321 aluminium alloy armour and 13 mm thick Bisalloy 360 armour steel plate test pieces were fastened to 38 mm APC aluminium alloy armour plate using both plain shank and plain-threaded shank fasteners, Figures 2(a) and 2(b). The alternative patch material, 13 mm armour steel plate, was chosen to give equivalent ballistic penetration resistance to the APC aluminium alloy armour.

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* Trade name of propellant driven stud/fastener system.

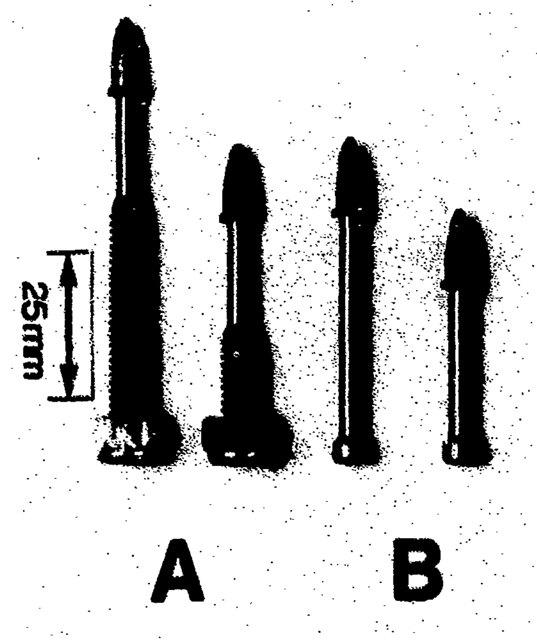

FIGURE 1 A. Plain/threaded shank Ramset fasteners for removable patches
B. Plain shank Ramset fasteners for permanent patches

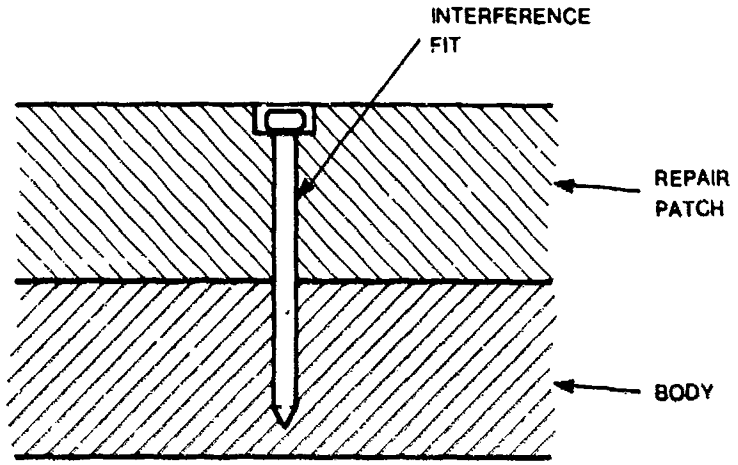

FIGURE 2A Schematic diagram of plain shank fastener repair patch fastening technique.

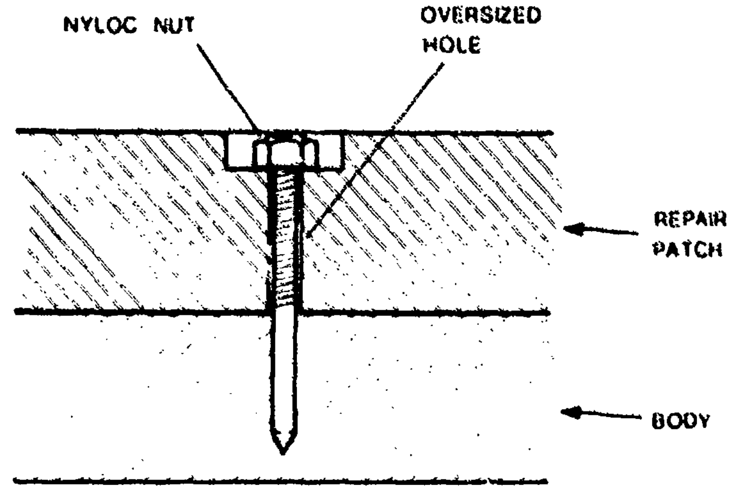

FIGURE 2B Schematic diagram of plain/threaded shank fastener repair patch fastening technique.

For the plain shank fasteners the diameter of the pilot holes was chosen to produce an interference fit of the fastener shank in the patch. Repair patch pilot holes for the plain-threaded shank fasteners were drilled over-size to allow easy removal of the patch if required and a recessed hole was provided to allow the Nyloc nut used in the assembly to be tightened to a position below the patch surface.

2.2 Leopard Tank Patch Repair

Attempts to penetrate a sample plate of Leopard Tank armour steel using the maximum hardness Ramset fasteners at the maximum charge level were unsuccessful and an alternative fastening system was sought based on an adhesive bonding process. Assessment of available adhesive systems against the high mechanical strength requirements of the repair patch/armour bond, ease of application of the patches and the severe shock and vibration present under service conditions indicated that a two part, high cure rate epoxy might be most suitable. From a survey of the properties of available epoxy resin adhesives a suitable candidate appeared to be CIBA-GEIGY Araldite Type 268/1.

Adhesive/steel tensile and shear bond strengths were measured using the techniques shown in Figures 3(a) and 3(b). To provide a standard surface treatment all bond surfaces were degreased using clean TFE (Tetrafluoroethylene) solvent after mechanical abrasion with 80 grit abrasive paper.

To evaluate the effects of the expected surface undulations in battle damaged hull armour and the consequent variation in adhesive thickness on tensile and shear bond strength, tensile and shear adhesive bond strength tests were performed with epoxy adhesive bond thicknesses varying from 2 to 6 mm.

2.3 Repair Patch Ballistic Trials

2.3.1 M113 APC Repair Patches

To assess the ballistic integrity of the MRL repair patches, fastened to M113 APC aluminium alloy armour hull, each type of patch and fastener combination were tested using the facility illustrated in Figure 4. Once fastened to the backing armour, which simulated a battle damaged APC hull, armour piercing .30 and .50 calibre rounds were fired at the patches at a range of 300 mm from an M1 Garand rifle and Browning machine gun respectively.

It was not thought necessary to ballistically test the repair patches against more powerful projectiles since both the .30 and .50 calibre AP rounds fully penetrate the standard aluminium side armour of the APC, at the range used.

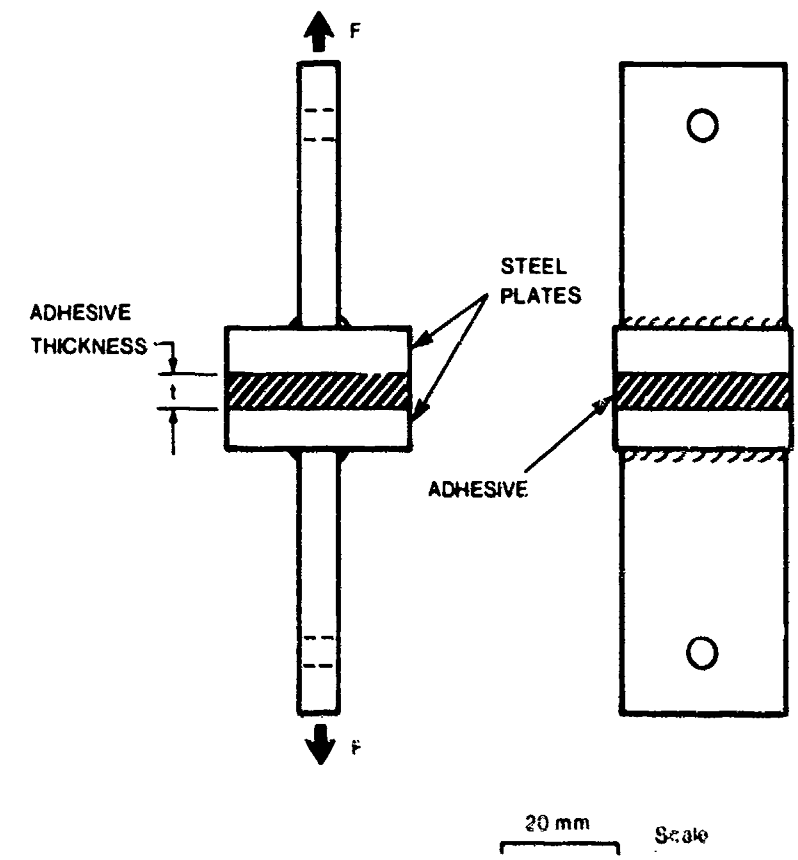

FIGURE 3A   Test fixture for tensile testing of epoxy adhesive.

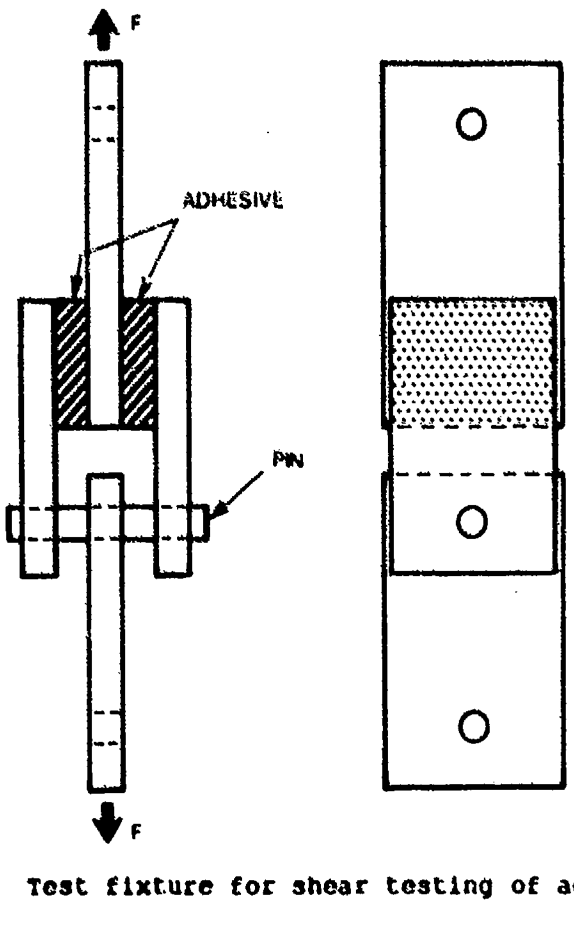

FIGURE 3B   Test fixture for shear testing of adhesive.

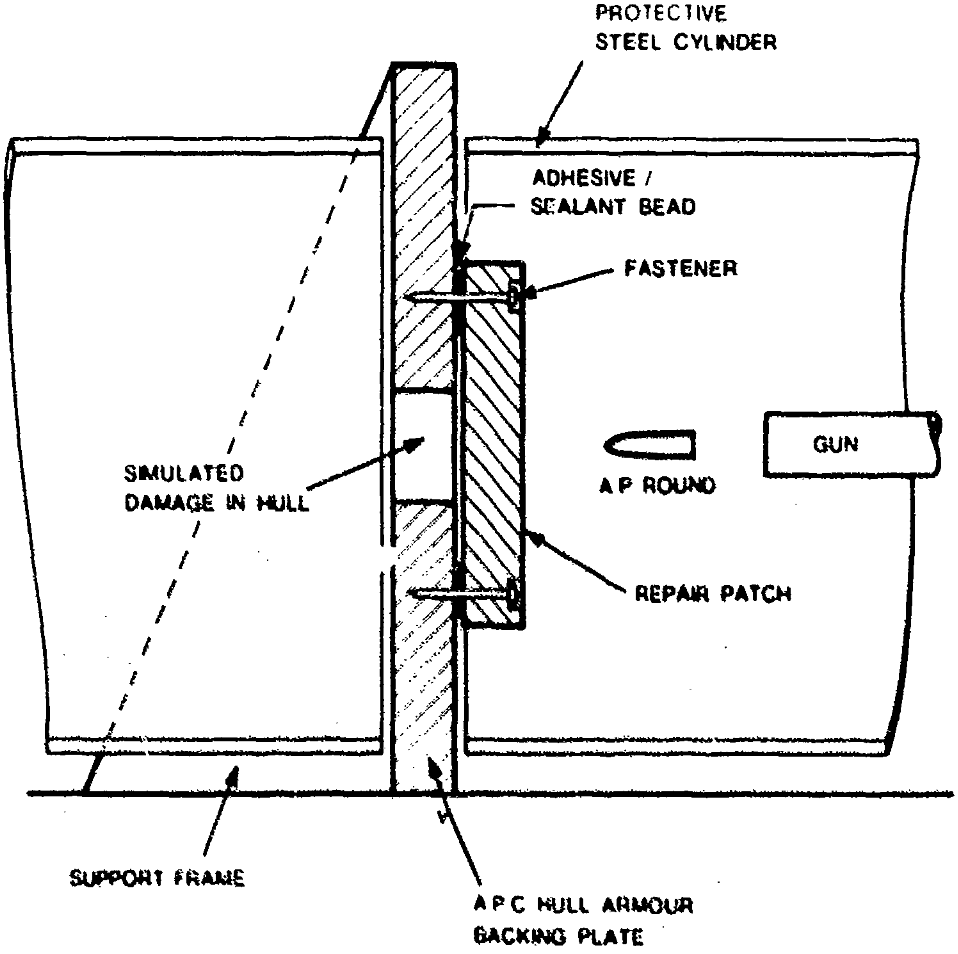

FIGURE 4   Schematic diagram of small-arms ballistic test rig.

2.3.2 *Leopard Tank Repair Patch*

Equivalent hardness and thickness armour steel to that used on the Leopard Tank was not available and ballistic testing could not be performed on this patch system.

3. FIELD TRIALS

3.1 *M113 APC Patch Repair*

For the adequate shock and vibration testing of the APC armour, patch repair technique and proposed sealant/adhesive system a trial was conducted using two M113 APCs.

On the 27th and 28th of June 1983 the two previously prepared sets of 300 mm x 300 mm steel (12.7 mm thick) and aluminium (39 mm thick) armour patches, Figure 5, were fastened to the sides of M113 APCs at RAEME Bandiana and Armoured Centre Puckapunyal using the Ramset techniques, Figures 6(a) and 6(b). All patches were applied to the APC hull sides after washing of the painted surface with clean water and drying with clean grease-free cloth.

For the trial at RAEME Bandiana all four patches were sealed using a continuous bead of commonly available commercial silicone based adhesive/sealant applied at 10-15 mm from the patch edge. An equivalent set of patches was applied to the M113 APC at Puckapunyal, however, two patches only were applied using the silicone sealant, while each of the remaining two patches were sealed with neoprene and acrylic based sealants respectively.

3.2 *Leopard Tank Patch Repair Trial*

On the 17th October 1983 two 13 mm thick 200 mm x 200 mm steel patches were applied to a Leopard Tank at Armoured Centre Puckapunyal. Surface preparation was accomplished by removal of all the paint from the tank hull, at the position chosen for the patch application, using an electric grinder followed by wiping with trichlorethylene solvent. The patches were then applied using the epoxy resin adhesive bonding system described earlier in this report.

The tank surfaces chosen for the application of the two patches were on the 45^{0} side armour and the 60^{0} lower frontal armour, Figure 7. Some difficulties were encountered during application of the patches especially in the frontal armour position where the adhesive allowed sliding of the patch before it was completely cured. This problem was overcome using a makeshift support which held the patch in place during curing of the adhesive.

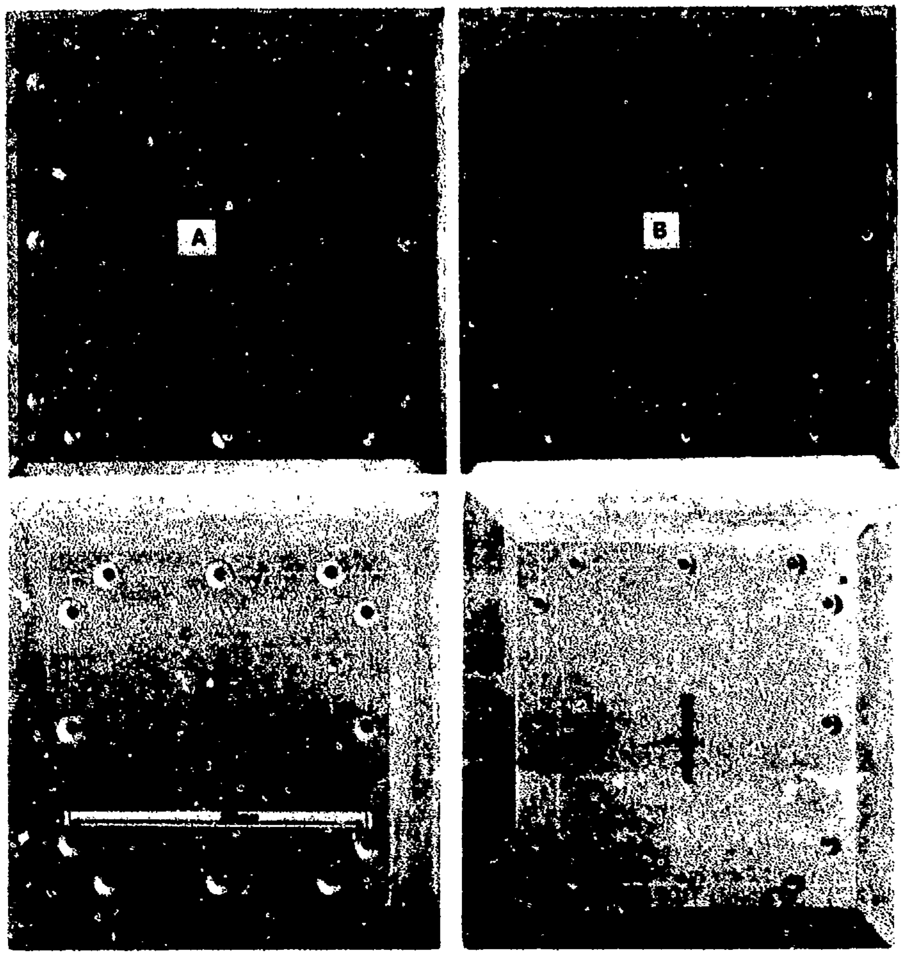

FIGURE 5 Steel (top) and aluminium (bottom) repair patches with appropriate fasteners. Pilot hole dimensional variation is evident for removable patches on left hand side and permanent patches on right hand side.

FIGURE 6A   Application of steel repair patches to APC.

FIGURE 6B   Steel and aluminium patches fastened to M113 APC.

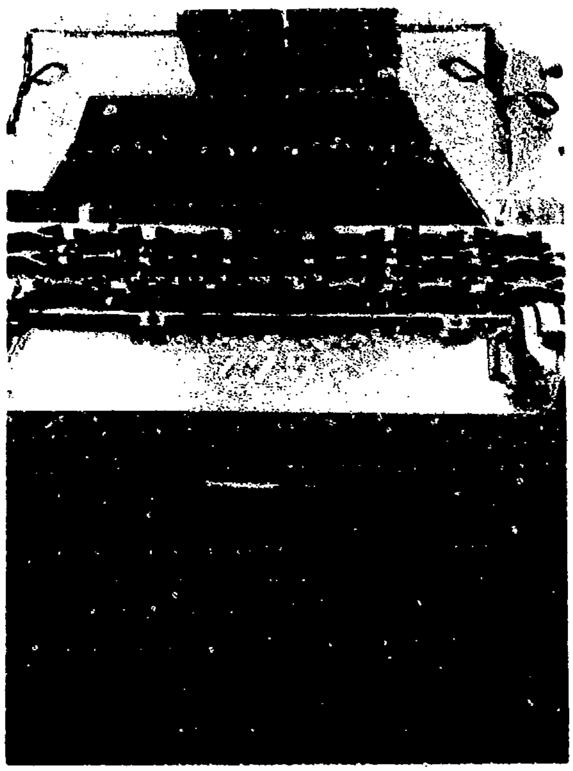

FIGURE 7 Steel repair patch fastened to Leopard Tank frontal armour.

3.3 Adhesive Tape Patch Repair Trials

The range of adhesive tapes used in these trials is described in Table I. These tapes were applied to the as-received painted sides of an APC, on the 17th October 1983 and checked for adhesive integrity one month after application. Pre-treatment of the APC side surfaces was by washing with clean water and drying using grease-free cloth. The APC adhesive tape test panel is shown in Figure 8.

TABLE I

Temporary Repair Adhesive Tape Types

Ident. No.	Description
1	Masking tape: paper backed, acrylic adhesive.
2	Packing tape: heavy duty paper backed, acrylic adhesive.
3	3M pressure sensitive tape: cloth backed, acrylic adhesive, green.
4	3M binding tape: pressure sensitive cloth backed, acrylic adhesive, red.
5	3M rubber sheet: pressure sensitive, acrylic adhesive, clear.
6	3M acrylic sheet: pressure sensitive, acrylic adhesive, clear.
7	3M reflecting tape: pressure sensitive, plastic backed, acrylic adhesive, red.
8	3M reflecting tape: pressure sensitive, plastic backed, acrylic adhesive, white.

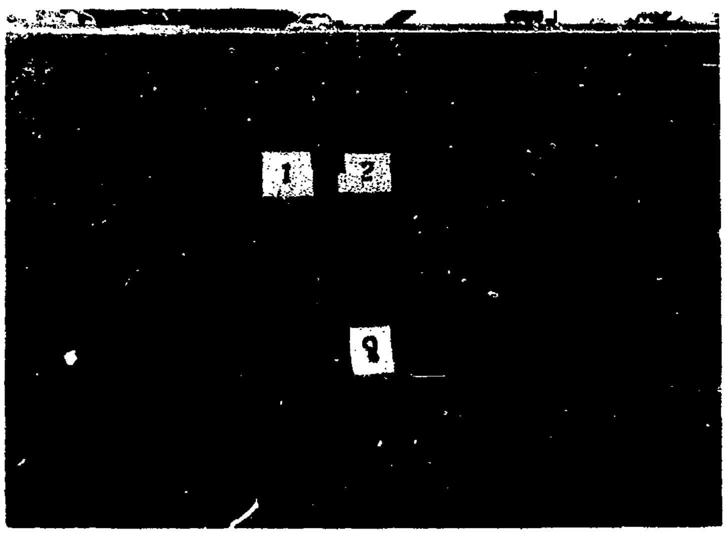

FIGURE 8 Temporary repair adhesive tape test panel on APC.

4. RESULTS

4.1 *Laboratory Results*

4.1.1 *Ramset Fastener System*

The optimum Ramset fastener/charge type combination was achieved using Ramset 2300 series plain shank and 2400 series plain/threaded shank fasteners with a 4 mm plain shank diameter and Ramset Type 225 charge. With these combinations it was possible to penetrate 28-32 mm of 5083 H321 aluminium alloy armour plate. The tensile force required to extract these fasteners averaged 16,000 N (3,600 lbf).

For the above Ramset fastener/charge combinations equivalent penetrator depths and extraction loads were measured on the aluminium to aluminium and steel to aluminium joined test pieces. Tightening of the Nyloc nut on the (unlubricated) threaded bolt fasteners using a torque wrench caused a torsional shear failure of the fastener at the plain/threaded shaft interface at a torque in excess of 25-30 Nm (18-22 ftlb). The maximum torque used on the bolted fastener system was consequently limited to 20 Nm (15 ftlb).

4.1.2 *Adhesive Bonding System*

Early tensile bond strength tests after 24 hour adhesive curing showed problems with inadequate mixing of the two part adhesive and extreme care was taken in following tests to ensure thorough mixing. The very short working time of the adhesive system, approximately 5 minutes at 20°C was an initial problem, however, with care and practice, mixing and application of the adhesive was completed well within the required working period.

The mean tensile strength of the epoxy adhesive was measured at 3.6 N/mm^2 with a minimum value of 2.7 N/mm^2 for bond thicknesses from 2 to 6 mm, Table II. The mean bond shear strength was 3.2 N/mm^2 with a minimum value of 1.5 N/mm^2, Table III. The extremely low minimum shear strength is attributable to inadequate adhesive mixing in a single test but is considered significant in illustrating the care required to attain maximum bond properties. For the majority of the tensile and shear tests the adhesive bond failed cohesively, within the bond material and not at the armour/adhesive interface thus indicating that the surface preparation used in these tests was adequate.

TABLE II

Tensile Test Results

CIBA GEIGY Araldite Type 268/1

Test	Adhesive Thickness mm	Tensile Strength N/mm^2
1	2	2.9
2	2	3.1
3	2	2.7
4	4	3.8
5	5	4.4
6	6	4.6

TABLE III

Shear Test Results

CIBA GEIGY Araldite Type 268/1

Test	Adhesive Thickness mm	Shear Strength (1) N/mm^2
1	1	2.9
2	2	4.8
3	3	3.4
4	4	1.5
5	5	3.0
6	6	3.6
7	7	3.3
8	8	2.5
9	9	3.6

Note: (1) Shear strength is for half of test specimen bond surface area only.

4.2 Field Trial Inspections

4.2.1 M113 APC Patch Repairs

The Ramset fastened patches on the M113 APCs were regularly inspected by Army personnel to determine patch fastener integrity. The authors also conducted inspections after periods of 4 and 5 months from the date of patch application.

All inspections indicated that the patches were mechanically sound. After the 5 month inspection one of the bolted patches on the APC at the Armoured Centre Puckapunyal was removed to check for the ingress of moisture and dust. Although the APCs had frequently been cleaned using high pressure water jets there was no moisture present under the patch indicating that the adhesive/sealant had performed satisfactorily. To the time of writing this report there had been no APC repair patch failures.

4.2.2 Leopard Tank Patch Repair

Regular inspection by Army personnel as well as MRL inspections at 1 month from the date of application of the two Leopard Tank adhesively bonded patches indicated that there were no problems with this patch repair technique and as of March 1985 there had been no reported Leopard Tank repair patch failures.

4.2.3 Adhesive Tape Patch Repair Technique

Inspection by Army and the authors up to September 1984 indicated that the majority of the adhesive tapes under trial showed good adhesion to the paint surface of the APC hull. Tape Types 1 and 2, Table I, however, showed slight deterioration due to the effect of moisture on the paper based backing of these tapes, while the acrylic based adhesive of tape Type 6 showed slight lifting at the edges.

4.3 Ballistic Trials Results

The results of the .30 and .50 calibre armour piercing trials on the Ramset patch repair system are shown in Figure 9. Both AP rounds penetrated the steel and aluminium patches, however, the integrity of the patch fastening system was not diminished.

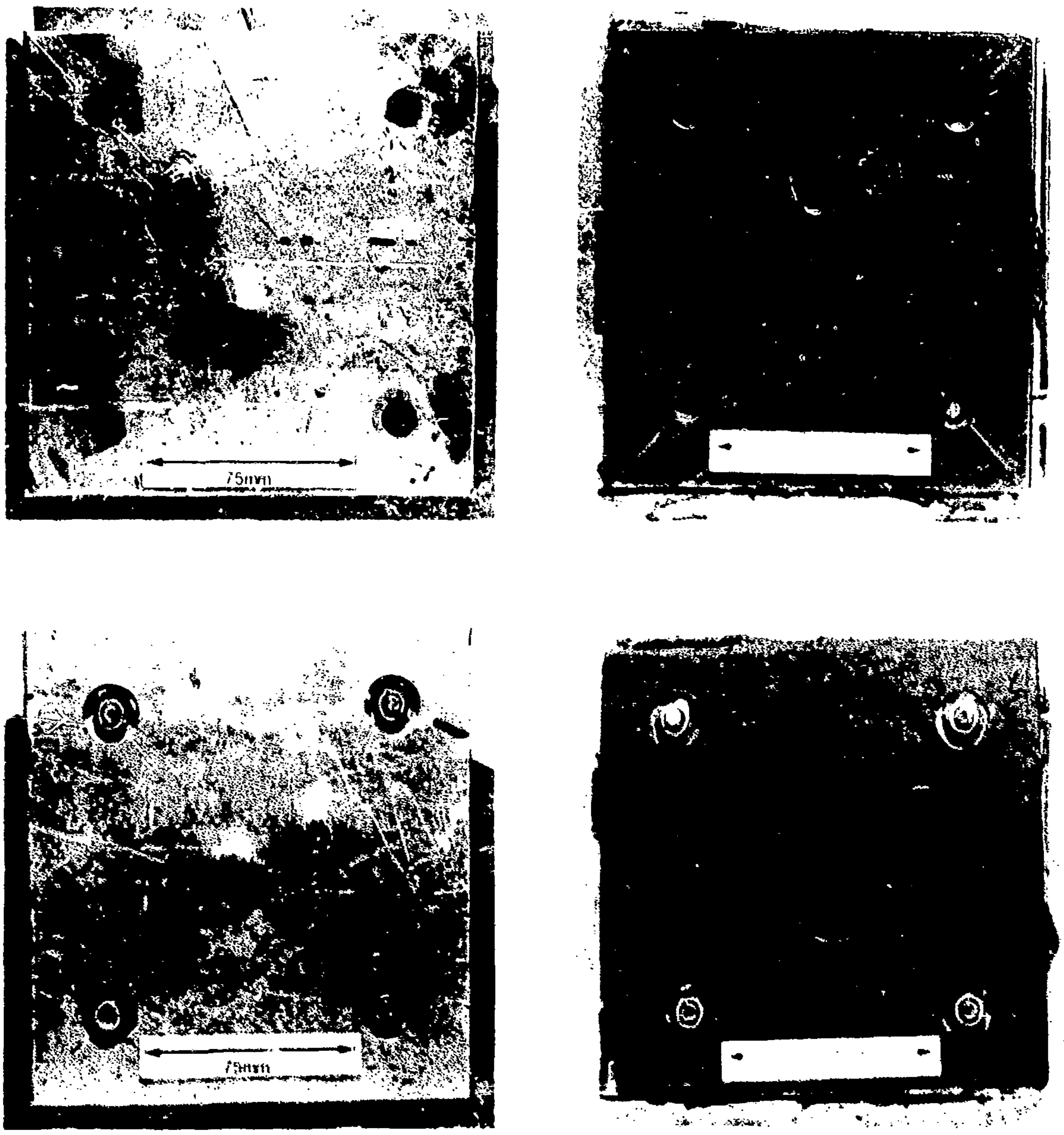

FIGURE 9 Aluminium and steel ballistic test patches showing .30 and .50 calibre AP round penetration.

5. DISCUSSION

5.1 Laboratory Results

5.1.1 Ramset Fastener System

Trials with plain shank and plain/threaded shank Ramset fasteners for the attachment of aluminium and steel armour plate to M113 APC aluminium armour indicated that this repair technique met the majority of the basic requirements stipulated in items (i) to (iv) in Section 1. Requirements (i), (ii) and (iii) were easily fulfilled by the compact size, versatility, ease of operation and high application speed provided by the Ramset system.

Using the results of the fastener penetration tests, repair patches with predrilled pilot holes were designed and machined from available 300 mm x 300 mm, 38 mm thick 5083 H321 aluminium alloy armour plate and 13 mm thick Bisalloy 360, steel armour plate for both the plain and plain/threaded shank fastener systems. The machined bevelled edges on the patches were included to reduce the likelihood of damage due to contact with obstructions such as trees and rock projections. The application times of both the permanent and easily removed bolted patches are very short requiring no more than ten minutes to apply for the patch, fastener and adhesive/sealant combinations given in this report.

Tensile extraction loads for the fasteners indicate that for the twelve fasteners used in the patch system shown in Figure 5 the total tensile patch/hull separation load would be at least 200,000 N. This is considered to be well in excess of the loading a patch of this mass would see in even the most severe service conditions. However, the effect of the shear stress and constant vibration imposed on the patch fasteners and joint in service is difficult to simulate in the laboratory and accordingly field trials were considered necessary.

The use of 38 mm thickness M113 APC aluminium armour patches, or thinner ballistically equivalent 13 mm armour steel patches should ensure that at least for a perpendicular projectile strike on the repaired M113 APC hull, the patches would ballistically approximate the original hull armour. Ballistic penetration tests using .30 and .50 calibre AP rounds against experimental aluminium and steel armour patches using the permanent and removable Ramset fastener systems indicated that there was no reduction in patch fastener integrity under these test conditions.

It was also considered that the application of a thin, flexible, non-corrosive, chemically inert adhesive/sealant film to the joint surfaces, using a simple cartridge and gun applicator, should provide complete sealing for air, water and NBC protection. In addition, this film would produce a degree of shock and vibration damping as well as patch adhesion and provide a sealed filler for uneven surfaces (a not uncommon feature of projectile and fragment damage on armour plate). Full evaluation of the effects of continuous shock and vibration on the effectiveness of this sealant/adhesive bond required field trials of patch repair systems.

5.1.2 *Adhesive Bonding System*

The two-part, high-curing rate adhesive chosen for the bonded repair system for the Leopard Tank was shown to have adequate laboratory adhesive performance and reasonable flexibility for this type of application. Additionally, when uncured, the adhesive will easily flow to fill interstices in damaged armour and for adequately prepared surfaces it will produce a tough strong bond.

5.2 *Field Trials*

The ability of the MRL developed forward battle field repair techniques for the M113 APC and Leopard Battle Tank to fulfil the majority of the basic requirements initially stipulated in this report have been demonstrated by limited field trials. These repair techniques have been shown to be fast and simple to use and for the armour patches offer a mechanically strong patch which can provide equivalent ballistic protection to the original armour in addition to excluding water when used with a suitable adhesive/sealant.

The original concept of the MRL battlefield repair technique envisaged a limited life for the patches, until a more permanent repair could be affected at a more convenient time. However, it is considered likely, in a combat situation, that the repair patches could remain on some vehicles for extended periods. To this end the armour repair patches on the two test vehicle types have been monitored in excess of their expected life and have shown long-term integrity up to a period of at least 17 months.

The adhesive tapes applied to the M113 APC have shown that it is possible to provide fast and simple temporary sealing of battle damaged armoured vehicles if the requirement arises.

Although the basic patch repair techniques have been developed and successfully applied it is now necessary to determine the optimum patch sizes and geometries for the two types of armoured vehicles as well as deciding on the final sealant/adhesive system and the selection of adhesive sealing tape. The final size and geometry of the armour patches will be dictated by the level of sustainable damage before an APC or tank will have to be backloaded for complete refitting. This damage level will also dictate the adhesive tape patch size required. A literature survey on the repair of armoured vehicles indicated a lack of information on the upper level of damage which could be sustained by an APC or tank before forward battlefield armour patching was no longer a viable repair technique.

Although the armour patch and temporary tape repair techniques have been shown to provide a degree of waterproofing, their ability to withstand NBC contaminants remains unknown and would require future testing to select the most suitable sealant and tape type.

6. CONCLUSIONS

A technique has been developed for rapid forward battlefield repairs to M113 APCs and Leopard Tanks. Repairs are performed by the application of armour patches to the battle damaged vehicle hulls using mechanical fastening or adhesive bonding systems. The patches can be designed to provide equivalent ballistic penetration resistance to the original vehicle hull armour.

Laboratory mechanical testing indicated a strong joint was achieved using proprietary Ramset fastening systems to afix predrilled aluminium or steel armour patches to M113 APCs. Good joint integrity has been demonstrated for an epoxy adhesive bonded steel armour patch for the repair of Leopard Tanks.

Field trials have been conducted to check the shock and vibration resistance of the repair techniques as well as the integrity of the proposed sealant/adhesive system. The success of these trials and the ballistic penetration testing indicated good mechanical performance of the patches.

The use of adhesive tape as a temporary sealing technique for water exclusion has been demonstrated and would provide a cheap system for emergency sealing of vehicle hulls against water and dust in combat situations.

In addition to its use in battle damage repair the MRL patch repair technique would also appear to be suited to the role of quickly providing increased armour protection for armoured vehicle hulls in a threat situation where the standard armour protection is inadequate.

7. RECOMMENDATIONS

Final selection and/or development of M113 APC and Leopard Tank battle damage patch repair kits and techniques requires Army to define the level of battle damage for each of these vehicles which will generally allow their forward repair.

The initial concept for use of the adhesive tape was to provide a method of quickly excluding water and dust, however, if the future use of an adhesive tape is to exclude NBC agents from a battle damaged armoured vehicle hull, further testing would be required to assess the permeability of these tapes to these agents. Similar NBC contamination exclusion testing would need to be performed for the adhesive/sealant used for the armour patch repair techniques.

The M113 APC and Leopard Tank repair patch trials should be continued to provide information on the long term effectiveness of the fastening techniques in providing a strong weatherproof patch.

8. ACKNOWLEDGEMENTS

The authors wish to thank the Army Maintenance Engineering Agency and Bandiana and Puckapunyal Army staff for their assistance with the field trials and consequent reporting of the condition of the repair patches. The authors are also indebted to Mr P.J. Pearce of the Organic Chemistry Division, MRL for his most helpful assistance and guidance in the selection and application of the sealants and adhesives used in this project.

9. REFERENCES

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