(12) UK Patent Application (19) GB (11) 2 344 411 (13) A

(43) Date of A Publication 07.06.2000

(21) Application No 9924501.1

(22) Date of Filing 15.10.1999

(30) Priority Data
(31) 09172477 (32) 15.10.1998 (33) US

(71) Applicant(s)
Stephen J E Boos
Orleans, Ontario, K1E 3K1, Canada

Charles A Williams
313 Springdale Drive, Bradenton, Florida 34210, United States of America

(72) Inventor(s)
Stephen J E Boos
Charles A Williams

(74) Agent and/or Address for Service
Gill Jennings & Every
Broadgate House, 7 Eldon Street, LONDON, EC2M 7LH, United Kingdom

(51) INT CL[7]
F41H 5/02

(52) UK CL (Edition R)
F3C CP2

(56) Documents Cited
US 4645720 A

(58) Field of Search
UK CL (Edition Q) B5N N394 N770 , F3C CMA CMB CP2
INT CL[6] F41H 5/02 5/04 7/02 7/04
Online: WPI, EPODOC, PAJ

(54) Abstract Title
Composite armour material

(57) A composite armour material comprises an outer layer of steel material with a hardness between 47 and 54 (Rockwell "C") and an inner layer of steel material with a hardness of between 28 and 36 (Rockwell "C") and a fracture toughness of 3.6 - 6.5 J/mm. The outer layer absorbs the ballistic impact of a projectile, and the inner layer absorbs the blast. The two layers are bonded together, preferably with a synthetic resin bonder such as a polysulphide based material or a polyurethane based material. A further layer of a composite of high tensile fibres together with a ductile polymer binder may be held in place adjacent to the inner layer, such that the material can stretch to trap any shrapnel which may penetrate the inner layer. A further outermost layer of applique material may also be attached, comprising two layers of mild steel sandwiching a layer of ceramic tiles.

GB 2 344 411 A

COMPOSITE ARMOR MATERIAL

FIELD OF THE INVENTION

This invention relates to a new composite material for use in vehicle armoring.

BACKGROUND OF THE INVENTION

Presently in North America armored vehicles are engineered and manufactured primarily to provide protection against ballistic attack. The armor typically comprises a single plate, and is held in place using mechanical fasteners and/or by welding. Ballistic protection is achieved either by overlapping of several armor plates, or by covering joints with additional plates. From a mechanical strength standpoint, these armor materials are basically parasitic and do not add any significant strength to the vehicle.

More recent advances in armor materials include the use of dual hard steel. The dual property hardness steel armor has several distinct advantages over earlier prior art armor; such advantages include having requirements conducive to unlimited production quantities using existing facilities and having fabricability and intrinsic properties of steel. The earlier concept for dual property steel armor was developed from the knowledge that a high hardness was needed to shatter steel armor piercing projectiles and a high toughness was required to achieve multiple strike integrity.

Although the dual property steel armor principle provides an alloy capable of breaking up the projectile, numerous tested alloys have resulted in panel shattering. When panel shattering occurs the effectiveness of the armor is lost, particularly as an armor suitable for a multiple strike capability.

A further development of armor materials is described in US patent no. 3,694,174, which issued on 26 September 1972. That patent discloses a composite material having an outer high hardness impact layer capable of breaking up a projectile, and a lower hardness tough backing layer capable of stopping the broken up projectile. The layers are hot-rolled together to form the composite. The difference in hardness being described as being in the range of 5-8 Rockwell C. The outer layer is further described as having a Rockwell C hardness of 58-59, and the inner layer having a Rockwell C hardness of 52-53. The thickness of the layers is described as being in the range of 2-3.5 inches.

It is apparent that both layers of this material are still relatively hard. Moreover, it is unlikely that the small relative difference in hardness between the two layers would be sufficient to achieve much of a difference in mechanical properties. Further, the hot-rolling process is bound to have an adverse impact upon such properties. Also, a composite of the described dimensions would add considerable weight to a vehicle. It will be appreciated that added weight will affect vehicle performance, particularly the power and handling requirements.

It is also known, for example, from US patent no. 4,948,673 issued 14 August 1990, to employ sintered ceramic tiles e.g. based on alumina or silica, to break up armor-piercing projectiles. The broken pieces of the projectile are then stopped by an armor plate backing.

SUMMARY OF THE INVENTION

According to the invention, a novel composite armor material is provided, comprising an outer ballistic impact resistant layer of a steel material having a Rockwell "C" scale hardness of 47-54, and an inner blast resistant steel layer

having a fracture toughness of 3.6-6.5 J/mm, and a Rockwell "C" hardness of 28-36.

Optionally, a synthetic resin adhesive is provided between the two layers. Depending upon the requirement, various adhesives may be employed. For example, a soft adhesive such as a polysulfide-based adhesive may be used in some embodiments and a harder adhesive such as a polyurethane-based adhesive may be used in other embodiments.

In another embodiment, a layer of a high tensile strength fabric material is provided adjacent to the inner layer. This layer is not bonded to the inner layer, since bonding would detract from its ballistic capability. Accordingly, it may be touching or slightly spaced from the inner layer and is held place by mechanical fasteners. Also, in use, some backing space must be provided to permit the material to flex so as to act as a catcher's mitt to trap any shrapnel which may have penetrated the inner layer.

In yet another embodiment, an additional outermost layer is provided, which is of a high hard steel as described above. In this case, no bonder is present, and the steel layers are welded together.

In a further embodiment, a ceramic layer may be included as an additional outermost layer.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The novel composite armor can be used to protect vehicle doors and roofs. It is comprised of a reasonably hard steel outer layer that is essential so that the lead core bullets and shrapnel meet sufficient resistance to be fundamentally changed or redirected. The subsequent layers can then trap the modified projectile. Yet this outer layer is not so hard that is shatters or

fails catastrophically as some ultra high hard steel armors would. A 3mm thick layer of Bulloy 500 or Compass B555, generally meeting U.S. military specification MIL-A-46100D, Armor plate, steel, wrought, high-hardness, has been found to be suitable.

The second layer of steel has been selected specifically for its toughness and ability to elongate a great deal before failure. Generally, these tough steels fall in line with U.S. military specification MIL-1-12560H, Armor plate, steel, wrought, homogenous, Class 2. Its primary role is absorbing great amounts of energy. This layer is also capable of being welded and not losing its mechanical properties as a result. A 3mm thick layer of Jessup 529 or Sanderson Kayser Class II, has been found to be suitable.

The optional bonding layer of 1-2 mm in thickness, may be a soft adhesive like polysulfide, or a harder adhesive like polyurethane. Specific examples of such adhesives are described in Table 1 which follows.

The big difference shown above is in tensile strength.

The adhesive plays a much greater role than merely holding the plates together. The adhesive distributes the impact energy over a greater area. It reduces the ability of the outer layer of steel to elongate in a direction normal to the applied force. It also adds the shear strength of the inner layer to that of the outer layer. Therefore, instead of allowing the outer layer of steel to fail independently in shear, the adhesive holds the plates together so that some of the shear strength of the inner plate is added to the outer. Thus, the ability of the outer plate to fail in shear or tension is reduced. This reduces the opportunity for local sites of high stress that are generated at the site of a failure. In addition, the adhesive acts as a medium through which the explosive shock waves must travel. As the waves pass through the outer plate, through the adhesive and then through the inner plate, they meet different levels of impedance. The changes in impedance disturbs the waves

and reduces their effect. The net effect of the energy distribution, the combined shear strengths and the shock wave disruption is a reduction in stress experienced by the armour system. This was most apparent when tests 5-1 and 5-3 were conducted. These tests were identical in armour materials, fabrication techniques and test procedures with the exception of the use of an adhesive. Test 5-1 did not have an adhesive between the layers of steel and the resulting depression in the door was 71 mm deep. Test 5-3 had a polysulfide adhesive between the layers of steel and the resulting depression was 57 mm deep. Therefore, it can be seen that the armour systems that employ adhesives between the layers of steel are capable of providing better protection.

The optional inner layer, of ballistic material is a composite comprising high tensile fibers laminated together with a ductile polymer binder e.g. Spectrashield®, having an aerial density of about 4.9 Kg/m^2. This material acts as a catcher's mitt to trap any fragments or pieces of the first two layers of armor that may have become dislodged. Its role is not one of absorbing large amounts of explosive energy but merely dealing with any material that gets through the first two layers. It is this layer that adds significantly to the penetration resistance of the high speed / high hardness shrapnel.

The mechanical structure is also unique.

The layers of armor are continuous. They are inserted into a vehicle door by cutting the rear face of the door open and inserting them. All other armor systems use at least two pieces of armor which are fastened together. All of the stress of the shock and overpressure is concentrated at the joint and it fails.

The method of welding the second layer of steel to the hinge pillar plate, the lock pillar plate, the door bottom plate and the beltline bar is unique in that it

involves a specific configuration of the welded joints.. If one of the welds is over stressed, the crack runs along the weld and out of the structure. Traditionally, armor manufacturers use straight welds which fail causing the armor plates to crack into the plate resulting in catastrophic failure. This system is the subject of our co-pending US application no. _____.

EXPERIMENTAL RESULTS

Test reports numbered 3E1, 3E3, 3F5, 4-1, 4-2, 4-6, 4-17, 4-18, 4-21, 5-1, 5-2, 5-3 and 5-4 are appended at the end of the application.

In Table 1 which follows entitled "Threats and Systems", we include the test results for various embodiments of our invention.

Table 1

Product	Polysulfide(Thiokol© MC-2326 Class A)	Polyurethane Essex® U-400SF
Shore A Hardness	60 maximum	55 - 60
Tensile Strength	> 1.38 Mpa	> 6.89 Mpa
Elongation	> 300 %	> 400 %

The test materials are as follows:

High hard steel = 3 mm layer of Sanderson Kayser Bulloy 500 (B500) or Sleeman Compass B555 (B555)

Bonder = 1 to 2 mm layer of Essex U-400SF (urethane) or Morton Aerospace Polymer Systems Thiokol® MC™ - 236 Class A (polysulfide)

Tough steel = 3 mm layer of Sanderson Kayser Military Vehicles and Engineering Establishment (MVEE) Class 2 (Class 2) or Jessop 529 (J529)

Spectra = 6 mm layer (4.9 kg/m^2)of Spectrashield®

Please note that the tests that have been conducted and were successful are noted with their test number, i.e. 3F5 or Yes and they are in bold font. The tests that would pass by extrapolation are in regular font and are identified by "EX".

Regarding the door armor system, the following convention will be used for the armor configuration:

System	Location	Materials
RU	Roof	High hard steel / urethane / tough steel
DU	Door	High hard steel / urethane / tough steel / Spectrashield
DP	Door	High hard steel / polysulfide / tough steel / Spectrashield
DO	Door	High hard steel / no bonder / tough steel / Spectrashield

The roof system RU was tested and provided protection against the M67 fragmentation grenade and the pipe bomb when they were detonated in contact (refer to tests 4-6, 4-18).

The three door armor systems DU, DP and DO were all tested with the pipe bomb in contact (refer to tests 3F1, 5-3, 5-1). It was found that the Spectrashield was not required to protect against this threat. Therefore, it can be concluded that the roof system would also be effective against the pipe bomb and the M67 grenade (when detonated in contact or close proximity) with polysulfide bonder or without any bonder.

Therefore, the armor configurations will be increased to include:

System	Location	Materials
RP	Roof	High hard steel / polysulfide / tough steel
RO	Roof	High hard steel / no bonder / tough steel

It was also found that the standard used for high harness shrapnel, a 9.5 mm diameter steel ball bearing, 63 Rockwell "C" hardness, did not penetrate the two layers of steel in door system DU when faced with the highest threat encountered. This threat was test 3F5. In it the ball bearings were accelerated toward the armor system by a 50 kg. 75% Forcite® dynamite, charge at a distance of 3.0 metres. Thus, the Spectrashield® was not required and the roof armor system would have sufficed.

The roof armor system has been ballistically tested with the same bullets and speed as the door systems but at an angle of forty-five degrees. This is a lower threat.

Accordingly, the roof armor system is good for:

- ballistic protection at forty-five degrees,
- M67 grenade and pipe bomb protection when detonated in contact and
- for protection against the 9.5 mm ball bearing accelerated by a 50 kg charge at 3.0 metres.

The addition of the Spectrashield would take the system to a higher standard:

- the roof system protection plus;
- ballistic protection at zero degrees of obliquity,
- fragment protection from pipe bombs at a stand off,
- a 2.3 kg non-directional charge at 0.5 metres and
- a 50 kg non-directional charge at 3.0 metres.

In some cases, the areas of an armored vehicle that are small in size do not lend themselves to the application of an inner layer of fibrous armor due to the fact that fibrous armor cannot provide protection right to the edge of the fibrous panel. In these areas, such as the roof rails (above the doors and windows but below the roof), useful protection can be achieved from the use

of steel armors alone. Accordingly another embodiment of the invention involves an armor system constructed by adding another (outer most) 3mm layer of high hard steel to the outside of the roof armour system. This three layer steel armour system provided the protection of:

- the roof system plus;
- ballistic protection at zero degrees of obliquity and
- a 50 kg non-directional charge at 3.5 metres (refer to test 4-1).

An even higher standard of protection is provided based on the results of test 4-21. In this test, a ceramic armor panel was placed on the threat side of door system DU. A pipe bomb was detonated in contact with the ceramic armor to ascertain whether or not that ceramic would create a fragmentation threat. The system passed.

As per test 4-21, the ceramic applique system consisted of an outer layer of 1.0 mm mild steel, 7.7 mm thick middle layer of Silicon Nitride ceramic tiles 101.6 mm square and an inner layer of 1.0 mm mild steel. The ceramic tiles were arranged in a staggered array and bonded to the outer and inner layers with polyurethane. The overall applique system was 610 mm high and 508 mm wide. It was held against the basic two layer steel armor system described above, with sheet metal screws inserted into the outer door skin.

Therefore, it appears that there are four levels of protection possible built on the same backbone:

Level 1 - Roof armor
Level 2 - Door armor
Level 3 - Roof Rail Armor
Level 4 - Door armor enhanced for higher levels of ballistic protection.

Ballistic Threats

Ballistic testing has taken place for all four door armor and roof rail systems and was successful in stopping the 5.56 mm M193 ball ammunition at muzzle velocity (991 +/- 8 m/s) at zero degrees of obliquity and the 7.62 mm M80 ball ammunition at muzzle velocity (838 +/-8m/s) at zero degrees of obliquity.

The roof system RU was tested with the same threats but at forty-five degrees. It passed easily and thus by extrapolation the other two roof systems should as well.

Armor piercing ammunition presents a higher ballistic threat. The door armor system DU was subjected to a pipe bomb test when a ceramic applique armor system was attached to the door, test 4-21. This test proved that the ceramics did not degrade the explosive resistance of the door in what is the hardest test. Therefore, it will be apparent to those skilled in the art, that the two other door systems would perform similarly.

Shrapnel

A 9.5 mm diameter steel ball bearing was selected as the standard for shrapnel testing because it is common for a terrorist to encase a non-directional bomb in high hardness shrapnel to enhance the effect of the blast. Usually this shrapnel is in the form of hardened nuts and bolts etc. However, it is extremely difficult to duplicate their impact characteristics in the laboratory because of their shapes. Thus, it was decided to use the ball bearing as the standard as it is relatively easy to propel at desired speeds and trajectories.

The highest threat faced with the ball bearing was the 50 kg non-directional charge at 3.0 metres. In test 3F5 is was shown that the ball bearings would penetrate the outer layer of steel but not the inner layer of steel. Thus, the

Spectrashield was not required to defeat this threat. The system tested was the door system DU.

The laboratory tests that were conducted with the ball bearing involved taking the ball bearing up to speeds of 1435 m/s. In these tests involving all three door armor systems, the ball bearings completely penetrated both layers of steel but not the Spectrashield. Therefore, it can be proven by extrapolation that all roof systems and all doors systems could defeat the ball bearing shrapnel threat of 50 kg non-directional charge at 3.0 metres.

The second type of shrapnel threat tested comes from a pipe bomb breaking into pieces at a close distance from the armor system. All three door armor systems were tested with the pipe bomb at a stand off and all three were successful in defeating the threat.

Explosive Device in Contact

The pipe bomb in contact was tested with the roof system RU and all three door systems. What was proven is that only the two layers of steel are required to defeat this threat. Therefore, all roof systems could be used against pipe bombs in contact.

Only roof system RU was tested against the hand grenade in contact, test 4-6. The inner layer of steel was depressed 25.4 mm and the system was far from failing. It would follow that all roof and door systems would defeat this threat as the minimum depression from a pipe bomb in contact was found to be 57 mm, test 5-1, door system DP.

Non-directional Charges

The threat from a bare non-directional charge comes primarily from the shock and over pressure. There were two very high threats that were tested, the 2.3 kg charge at 0.5 metres and the 50 kg charge at 3.0 metres. In both cases the door system DU was tested. In test 3E3 the door was depressed 57 mm by the 2.3 kg charge. The same door was retested with the 50 kg charge in test 3F5 and was found to be depressed 76 mm.

If one considers the fact that the pipe bomb places the greatest amount of stress in a localized area on the door and the pipe bomb depressions for all three door systems are in the same order of magnitude, it would follow that all three door armor systems could handle the 2.3 kg charge at 0.5 metres and the 50 kg charge at 3.0 metres. The only reason door armor systems DP and DO were not tested at these higher threats was merely a resource issue and not a technical issue.

Mechanical Properties

The outer layer of steel was selected for the fact that it was not so hard (ultra high hard, minimum 57 Rockwell "C" scale) that it would shatter and cause catastrophic failure but that it was hard enough (high hard 47-51 Rockwell "C" scale) to fundamentally change or re-direct lead core bullets or shrapnel. Generically, these high hard steels fall in line with the aforementioned U.S. military specification 46100. Mechanical tests were conducted on the steels used as the outer layer and the results are shown in Table 3 titled "Mechanical Test Results". The hardnesses ranged from 47 to 51 Rockwell "C" scale, the ultimate tensile strengths from 1559 to 1688 Mpa, the percent elongation from 13.7 to 19.9 and the fracture toughness from 3.4 to 3.8 J/mm. Preferably, the hardness for this outer layer is 49-51 Rockwell "C" scale.

The inner layer of steel was selected from steels that offer toughness so that the shock of the blast and the impact of shrapnel do not cause these steels to fail. Generically, these tough steels fall in line with U.S. military specification MIL-A-12560H, Armor plate, steel, wrought, homogeneous, Class 2.

Mechanical tests were conducted on the steels used as the inner layer and the results are also shown in Table 3. The hardnesses ranged from 30 to 36 Rockwell "C" scale, the ultimate tensile strengths from 980 to 1101 Mpa, the percent elongation from 13.6 to 17.2 and the fracture toughness from 3.8 to 6.5 J/mm. Although the tests were successful with these steels, the preferred steel for this application would be 28-30 Rockwell "C" scale and have a fracture toughness of 5.4-6.5 J/mm. These steels do not lose their mechanical properties as dramatically as the high hard steels when welded and were, therefore, able to be used very effectively as structural members as well as armor plate.

In applications where greater ballistic resistance is required, and the use of ceramic or fibrous armors is impractical or cost prohibitive, a second 3 mm thick outer layer of the high hard steel is included. In this embodiment, the composite comprises three layers of steel, the outer two layers being of the high hard steel and the inner layer being of the high toughness steel materials as described above. The layers are welded together by edge and/or plug welds, with no bonder being present. See Tables 2 and 3 for test data.

Tables 2 and 3 are followed by sets of Explosive Test Data.

Table 2
Threats and Systems

		Roof	Roof	Roof	Door	Door	Door	Roof rail
	System :	**RU**	**RP**	**RO**	**DU**	**DP**	**DO**	
	Outer layer	High hard steel	High hard steel	High hard steel	High hard steel	High hard steel	High hard steel	High hard steel
	Bonder	Urethane bonder	Polysulpide bonder	No bonder	Urethane bonder	Polysulpide bonder	No bonder	No bonder
	Inner layer	Tough steel	Tough steel	Tough steel	Tough steel	Tough steel	Tough steel	High hard steel
	Inmost layer				Spectra	Spectra	Spectra	Tough steel
ID	Threat							
1. Ballistic								
1.A.	5.56 mm M193 @ 991 +/- 8 m/s	45 degrees B555+ J529	EX - 45 degrees	EX - 45 degrees	O degrees B555 + J529 B500 + Class 2 B500 + J529	O degrees B555 + J529 B500 + Class 2 B500 + J529	O degrees B555 + J529 B500 + Class 2 B500 + J529	O degrees B555 + B555 + J529
1.B.	7.62 mm M80 @ 838 +/- 8 m/s	45 degrees B555+ J529	EX - 45 degrees	EX - 45 degrees	O degrees B555 + J529 B500 + Class 2 B500 + J529	O degrees B555 + J529 B500 + Class 2 B500 + J529	O degrees B555 + J529 B500 + Class 2 B500 + J529	O degrees B555 + B555 + J529
1.C.	Higher threats				*** 4-21 B500 + Class 2	EX	EX	
2. Shrapnel								
2.A.1	9.5 mm ball bearing Rc 63 propelled by 50 kg of 75% Forcite at 3.0 metres	3F5 B500 + J529	EX	EX	3F5 B500 + J529	EX	EX	
2.A.2	9.5 mm ball bearing Rc 63 propelled by 50 kg of 75% Forcite at 5.0 metres						4-2 B500 + J529 B555 + J529	
2.A.3	9.5 mm ball bearing Rc 63 propelled by ballistic test setup at 1435 m/s				Yes B555 + J529	Yes B555 + J529	Yes B555 + J529	Yes - 1171 m/s B555 + B555 + J529

Table 2 (Cont.)
Threats and Systems

		Roof	Roof	Roof	Door	Door	Door	Roof rail
	System :	**RU**	**RP**	**RO**	**DU**	**DP**	**DO**	
2.B.	Fragments from 51mm diameter steel pipe bomb propelled by 454 grams of smokeless powder at a stand off of 305 mm				4-17 B500 + J529	5-4 B555 + J529	5-2 B555 + J529	
3. Explosive Device In Contact								
3.A.	51mm diameter steel pipe bomb propelled by 454 grams of smokeless powder	4-18 B500 + J529	5-3 B555 + J529	5-1 B555 + J529	3E1 B500 + J529	5-3 B555 + J529	5-1 B555 + J529	
3.B.	M67 handgrenade	4-6 B555 + J529	EX	EX	EX	EX	EX	
4. Non-Directional Charges								
4.A.	2.3 kg @ 0.5 m				3E3 B500 + J529	EX	EX	
4.B.	50 kg @ 3.0 m				3F5 B500 + J529	EX	EX	4-1@3.5m B555 + B555 + J529
4.C.	50 kg @ 5.0 m						4-2 B500 + J529 B555 + J529	

B555 = Sleeman Compass B555

B500 = Sandserson Kayser Bulloy 500
Class 2 = Sanderson Kayser Military Vehicles and
Engineering Establishment (MVEE) specification 816 Class 2

529 = Jessop 529

Table 3
Mechanical Test Results

Steel	Heat Lot	Hardness Rockwell "C"	Hardness Brinell	Ultimate Tensile Strength(MPa)	% Elongation	Fracture Toughness (J/mm)
High hard steels						
Bulloy 500	LV8103	51 (conversion)	492	1667	13.8	
Bulloy 500	LV8150	50		1564	13.7	
Compass B555	468613-30	47		1559	14.9	3.7-4.0
Compass B555		49.5		1688	19.9	3.3-3.5
Tough steels						
MVEE Class 2	LV8144	32 (conversion)	302	1041	15.0	6.5 *
Jessop 529	OMW32HH	30.5		993	13.6	5.4-5.9
Jessop 529		36		1101	17.2	3.6-3.8

* assuming that Sanderson Kayser used a 10 mm deep sample with a 2 mm deep notch when conducting impact tests. Their result was 0.81 J/mm2

TEST IDENTIFIERS

Test Series	3E
Site	Val des Monts
Date	96-01-23

PROCEDURE

Objective	To determine if 3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel and Backed with 4.9 kg/m2 (1.0 psf) of Spectrashield can be used as an armour system in an automotive door to provide protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder.
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 oz.)
Charge Name	Smokeless powder
Charge Manufacturer	Bullseye
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	Contact
Charge Location	Door
Vehicle	Test Fixture
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 in.) Sanderson Keyser Bulloy 500 steel
A-Bonder/Gap 1	Urethane
A-Layer 2	3 mm (1/8 in.) Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	1 mm (0.04 in.) aluminum
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	

B-Witness Panel	
Procedure Notes	Pipe bomb suspended against the door skin with its axis parallel to the vehicle's axis. Pipe located adjacent to the centre of the lower half of the door. Detonator inserted in end of pipe closest to the front of the vehicle. Door complete with glazing.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	360 mm (14.0 in.) hole and bottom pulled away
C-Outer Layer 1	Depressed but intact
C-Bonder/Gap 1	
C-Layer 2	Intact
C-Bonder/ Gap 2	
C-Layer 3	Intact
C-Witness Panel	No marks
D-Armour Location 2	RF Door Glazing
D-OEM Layer	
D-Outer Layer 1	Triplex 45 mm (1.8 in.) glazing c/w polycarbonate
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	
High Speed Film	
High Speed Video	

Observation Notes	The door skin was pulled away from the door at the bottom. The pipe bomb pressed a portion of the door skin into the armour at the site of the depression. The depth of the depression at the conclusion of this test is not known, however, the door was subjected to three more tests and the depression eventually reached 79 mm (3.1 in.) (Refer to tests 3E2, 3G5 and 3G6).The door was basically intact. There were four lobes on the beltline bar in the door. The lobes were reinforced with gussets protruding right to the lower edge of the lobes. One of the lobes close to the site of impact pushed the inner layer of armour through the outer layer so that the outer layer had a semi-circular crack. This crack is not considered a system failure. The glazing was cracked but was still intact.

CONCLUSIONS

Conclusions	A vehicle occupant would not have been harmed by flying debris or mechanical failure. 3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel backed with 4.9 kg/m2 (1.0 psf Spectrashield) can be used as an armour system in an automotive door to provide protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder.

RECOMMENDATIONS

Recommendations	3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel backed with 4.9 kg/m2 (1.0 psf Spectrashield) should be used as an armour system in an automotive door to provide protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder. The gussets on the beltline bar lobes should be shortened to allow the lobes to hinge a bit.

TEST IDENTIFIERS

Test Series	3E
Site	Val des Monts
Date	96-01-23

PROCEDURE

Objective	To determine if 3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (1.0 psf) of Spectrashield can be used as an armour system in an automotive door to provide protection against the shock and overpressure effects of a 2.27 kg (5.0 lb.) non-directional charge detonated at a distance of 0.5 m (20 in.).
Charge Information	
Charge Type	Non-directional
Charge Weight	2.27 kg (5.0 lb.)
Charge Name	75 % Forcite dynamite
Charge Manufacturer	
Charge Lot	
Pipe Size	
Stand Off	0.5 m (20 in.)
Charge Location	Door
Vehicle	Test Fixture
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 in.) Sanderson Keyser Bulloy 500 steel
A-Bonder/Gap 1	Urethane
A-Layer 2	3 mm (1/8 in.) Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	1 mm (0.04 in.) aluminum
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	

B-Layer 3	
B-Witness Panel	
Procedure Notes	The charge was placed in the trunk of a vehicle which was placed so that the charge would impact the centre of the armoured door. An opening was placed in the trunk to further direct the charge to the armoured door.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	Numerous impacts and penetrations
C-Outer Layer 1	58 mm (2.28 in.) depression - no penetrations
C-Bonder/Gap 1	
C-Layer 2	No penetrations or cracks, some depression
C-Bonder/ Gap 2	
C-Layer 3	No penetrations
C-Witness Panel	No marks
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	
High Speed Film	

High Speed Video	
Observation Notes	The door was intact. The door skin was pressed against the armour system and penetrated in many areas. The outer layer of armour was depressed 58 mm (2.28 in.) and had two areas of notable impact close to the centre of the door. These areas were circled in silver paint for future reference as the door would be retested. The two areas of impact were also visible on the inside of the second layer of steel. They were also marked with silver paint for future reference. The Spectra was not damaged although it had been impacted by the second layer of steel.

CONCLUSIONS

Conclusions	This system provides excellent protection against the threat of the shock and overpressure effects of a 2.27 kg (5.0 lb.) non-directional charge detonated at a distance of 0.5 m (20 in.) An occupant would not have been harmed by flying debris or mechanical failure.

RECOMMENDATIONS

Recommendations	If protection is required against the shock and overpressure effects of a 2.27 kg (5.0 lb.) non-directional charge detonated at a distance of 0.5 m (20 in.), 3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel should be used.

TEST IDENTIFIERS

Test Series	3F
Site	Petawawa
Date	96-04-11

PROCEDURE

Objective	To determine if the door armour system could provide protection against the shock and overpressure of a 50 kg (110 pound) non-directional charge placed 3.0 m (10 feet) from the vehicle. Also, to determine if the armour system could prevent the penetration of steel ball bearings propelled by the same charge.
Charge Information	
Charge Type	Non-directional with shrapnel
Charge Weight	50 kg (110 pound)
Charge Name	75 % Forcite dynmanite
Charge Manufacturer	
Charge Lot	
Pipe Size	
Stand Off	3.0 m (10 feet)
Charge Location	Side
Vehicle	Test Fixture
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	1 mm (0.04 inches) mild steel
A-Outer Layer 1	3mm (1/8 inch) Sanderson Keyser Bulloy 500
A-Bonder/Gap 1	Urethane
A-Layer 2	3mm (1/8 inch) Jessop 529
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	1 mm (0.038 inches) aluminum
B-Armour Location 2	RF Door
B-O-OEM Layer	
B-Outer Layer 1	Triplex 45 mm (1.77 inches) glazing s/n SG26842
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	
B-Witness Panel	Nil

Procedure Notes	The charge was placed in the trunk of a vehicle placed so that the charge was closest to the ""B"" pillar on the test fixture. The fender of this vehicle was cut open to expose the charge and preferentially direct it towards the test fixture. The ball bearings (63 Rockwell ""C"" scale) were taped to the exterior of the charge facing the test fixture. NOTE: This door was previously tested with a 2.3 kg (5.0 pound) non-directional charge, test no. 3E3. It had sustained a large depression in the outer layer 58 mm (2.28 inches) deep from the pressure and two smaller yet deeper depressions from shrapnel. These smaller depressions were marked with silver paint."

OBSERVATIONS

Survive	No
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	Intact but penetrated many times by shrapnel
C-Outer Layer 1	Slight deperession - one penetration
C-Bonder/Gap 1	
C-Layer 2	No penetrations
C-Bonder/ Gap 2	
C-Layer 3	No penetrations
C-Witness Panel	No penetrations
D-Armour Location 2	RF Door
D-OEM Layer	Pushed out of frame at top, inner layer intact
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	

High 8mm	
8mm	
VHS	
SVHS	
High Speed Film	
High Speed Video	
Observation Notes	The glazing was forced through the frame at the top and came to rest on the test fixture. The polycarbonate inner layer was not penetrated. The lower half of the door was impacted by at least 30 pieces of shrapnel including 6 ball bearings. The outer steel layer was penetrated by one ball bearing but it was stopped by the second steel layer, the Spectra was not required to stop this threat. The steel armour was depressed 76 mm (3.0 in.) in the center but maintained its structural integrity.

CONCLUSIONS

Conclusions	The glazing frame needs to be reinforced. The lower half of the door performed well and completely defeated the non-directional and high hardness shrapnel threats, this system does not need further development.

RECOMMENDATIONS

Recommendations	The three layer armour system can be used in the lower half of the door to defeat the shock and overpressure of a 50 kg (110 pound) non-directional charge placed 3.0 m (10 feet) away. It can also be used to defeat high hardness shrapnel propelled by the same charge. The glazing is sufficient for this threat but the frame system requires further development.

TEST IDENTIFIERS

Test Series	4
Site	DREV
Date	

PROCEDURE

Objective	To determine if the armour systems could provide protection against the shock and overpressure of a 50 kg (110 pound) non-directional charge placed 3.5 m (11.5 feet) from the vehicle. Also, to determine if the armour systems could prevent the penetration of steel ball bearings propelled by the same charge.
Charge Information	
Charge Type	Non-directional with shrapnel
Charge Weight	50 kg (110 lb.)
Charge Name	75 % Forcite dynamite
Charge Manufacturer	
Charge Lot	
Pipe Size	
Stand Off	3.5 m (11.5 feet)
Charge Location	Right Side
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	Right Side Roof Rail and Sail Panel
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 in.) Compass B555
A-Bonder/Gap 1	Nil
A-Layer 2	3 mm (1/8 in.) Compass B555
A-Bonder/ Gap 2	Nil
A-Layer 3	3 mm (1/8 in.) Jessop 529 steel
A-Witness Panel	Screen
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	
B-Witness Panel	

Procedure Notes	The charge was placed in the trunk of a vehicle that was positioned so that the centre of the charge would be directed at the ""B"" pillar of the armoured vehicle. The sides of the trunk were cut to further focus the charge on the armoured vehicle. 9.5 mm (3/8 in.) diameter ball bearings, 63 Rockwell ""C"" hardness, were taped to the side of the charge adjacent to the armoured vehicle."

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	Right Side Roof Rail and Sail Panel
C-OEM Layer	Several perforations
C-Outer Layer 1	Intact
C-Bonder/Gap 1	
C-Layer 2	Intact
C-Bonder/ Gap 2	
C-Layer 3	Intact - no penetrations
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	

High Speed Film	
High Speed Video	
Observation Notes	Several pieces of shrapnel impacted the sail panel but did not cause any penetrations into the vehicle. There weren't any impacts of ball bearings on the roof rail or sail panel that were located. The roof rail and sail panel appeared unchanged by the test.

CONCLUSIONS

Conclusions	The three layer steel armour system is capable of providing protection against the shock and overpressure of a 50 kg (110 pound) non-directional charge placed 3.5 m (11.5 feet) from the vehicle and from shrapnel propelled by the same charge.

RECOMMENDATIONS

Recommendations	This system is complete and may be used in its present configuration. No further testing required.

TEST IDENTIFIERS

Test Series	4
Site	DREV
Date	96-07-04

PROCEDURE

Objective	To determine if the armour systems could provide protection against the shock and overpressure of a 50 kg (110 pound) non-directional charge placed 5.0 m (16.4 feet) from the vehicle. Also, to determine if the armour systems could prevent the penetration of steel ball bearings propelled by the same charge.
Charge Information	
Charge Type	Non-directional with shrapnel
Charge Weight	50 kg (110 lb.)
Charge Name	75 % Forcite dynamite
Charge Manufacturer	
Charge Lot	
Pipe Size	
Stand Off	5.0 m (16.4 feet)
Charge Location	Left Side
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	LF Door
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 in.) Sanderson Keyser Bulloy 500 steel
A-Bonder/Gap 1	Urethane
A-Layer 2	3 mm (1/8 in.) Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	Screen
B-Armour Location 2	Left Side ""B"" pillar"
B-O-OEM Layer	1 mm (0.04 in.) mild steel
B-Outer Layer 1	3 mm (1/8 in.) Jessop 529 steel
B-Bonder/Gap 1	50 mm (2 in.) to 100 mm (4 in.)
B-Layer 2	3 mm (1/8 in.) Sanderson Keyser Bulloy 500 steel
B-Bonder/ Gap 2	Nil - plug welded together
B-Layer 3	3 mm (1/8 in.) Jessop 529 steel
B-Witness Panel	Screen

Procedure Notes	The charge was placed in the trunk of a vehicle that was positioned so that the centre of the charge would be directed at the ""B"" pillar of the armoured vehicle. The sides of the trunk were cut to further focus the charge on the armoured vehicle. 9.5 mm (3/8 in.) diameter ball bearings, 63 Rockwell ""C"" hardness, were taped to the side of the charge adjacent to the armoured vehicle."

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	LF Door
C-OEM Layer	Numerous impacts and penetrations
C-Outer Layer 1	One ball bearing penetration
C-Bonder/Gap 1	
C-Layer 2	No penetrations
C-Bonder/ Gap 2	
C-Layer 3	No penetrations
C-Witness Panel	No penetrations
D-Armour Location 2	Left Side ""B"" pillar"
D-OEM Layer	Numerous impacts and penetrations
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	No access to observe
D-Bonder/ Gap 2	
D-Layer 3	No penetrations
D-Witness Panel	No pentrations
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	

High Speed Film	
High Speed Video	
Observation Notes	The vehicle basically remained intact although the sheet metal was pressed up against the armour systems. There were three discernable impacts of ball bearings on the front door. One of them penetrated the outer layer of steel and was trapped by the second layer of steel. The vehicle was moved sideways and rearward, the left rear wheel moved the most, 1.2 m (3.9 ft.) left and 0.5 m (1.6 ft.) to the rear. The armour systems did not seem to be affected by the over pressure.

CONCLUSIONS

Conclusions	The armour systems provided complete protection against the shock and over pressure of the 50 kg (110 lb.) non-directional charge when detonated at a distance of 5.0 m (16.4 ft.). The armour systems also prevented the high hardness shrapnel from entering the vehicle.

RECOMMENDATIONS

Recommendations	These armour systems should be used if protection is required against the shock and over pressure of a 50 kg (110 lb.) non-directional charge when detonated at a distance of 5.0 m (16.4 ft.).

TEST IDENTIFIERS

Test Series	4
Site	DREV
Date	96-07-03

PROCEDURE

Objective	To determine if 3 mm (1/8 inch) of Compass B555 steel bonded with urethane to 3 mm (1/8 inch) of Jessop 529 steel could be employed as roof armour to stop the threat of a M67 grenade when detonated in contact with the roof pan.
Charge Information	
Charge Type	Hand grenade M67 fragmentation
Charge Weight	185 grams (6.5 ounces)
Charge Name	Composition ""B"""
Charge Manufacturer	
Charge Lot	
Pipe Size	
Stand Off	Contact
Charge Location	Roof
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	Roof over RR passenger
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 inch) of Compass B555 steel
A-Bonder/Gap 1	Urethane
A-Layer 2	3 mm (1/8 inch) of Jessop 529 steel
A-Bonder/ Gap 2	
A-Layer 3	
A-Witness Panel	DREV standard witness pack
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	
B-Witness Panel	

	bottom of the depression was an ""H"" shaped crack. The inner layer was not ruptured or cracked but was depressed approximately 25.4 mm (1.0 inch)."

CONCLUSIONS

Conclusions	3 mm (1/8 inch) of Compass B555 steel bonded with urethane to 3 mm (1/8 inch) of Jessop 529 steel and employed as roof armour will stop the threat of a M67 grenade when detonated in contact with the roof pan.

RECOMMENDATIONS

Recommendations	If protection in the roof (or other areas) is required against the M67 grenade when detonated in contact, the armour system should be comprised of 3 mm (1/8 inch) of Compass B555 steel bonded with urethane to 3 mm (1/8 inch) of Jessop 529 steel.

Procedure Notes	The grenade was placed on the roof in the centre of the right rear quadrant with the fuse facing upward. A witness pack was suspended 127 mm (5.0 in.) below the roof.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	Roof over RR passenger
C-OEM Layer	One large penetration
C-Outer Layer 1	Depression - no penetration
C-Bonder/Gap 1	
C-Layer 2	Depression - no penetration
C-Bonder/ Gap 2	
C-Layer 3	
C-Witness Panel	No marks
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	
High Speed Film	
High Speed Video	
Observation Notes	The outer layer was depressed approximately 140 mm (5.5 in.) in diameter and 26 mm (1.0 inch) deep at the centre. At the

TEST IDENTIFIERS

Test Series	4
Site	DREV
Date	98-07-03

PROCEDURE

Objective	To determine if 3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (1.0 psf) Spectrashield could prevent the penetration of the shrapnel created by a pipe bomb filled with 454 g (16 oz.) of smokeless powder detonated 305 mm (12 in.) from the armour.
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 oz.)
Charge Name	Smokeless powder
Charge Manufacturer	Winchester 231
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	305 mm (12 in.)
Charge Location	Door
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 in.) Sanderson Keyser Bulloy 500 steel
A-Bonder/Gap 1	Urethane
A-Layer 2	3 mm (1/8 in.) of Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	Screen
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	

B-Witness Panel	
Procedure Notes	The pipe bomb was hung on a frame so that its longitudinal axis was parrallel to that of the vehicle and the bomb was 305 mm (12in.) from the center of the lower half of the door. NOTE: This door had already been tested in test no. 4-1. There was a 15 mm (0.6 in.) penetration of the two steel layers but not the Sprectrashield prior to test 4-17.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	Large number of penetrations
C-Outer Layer 1	Split 16 mm (0.6 in.) by 178 mm (7.0 in.)
C-Bonder/Gap 1	
C-Layer 2	Split as per Outer Layer 1
C-Bonder/ Gap 2	
C-Layer 3	Impacted by one piece of shrapnel, no penetration
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	

High Speed Film	
High Speed Video	
Observation Notes	The pipe bomb broke into pieces with a wide range of sizes. The most significant impact was made by the largest piece that split the two steel layers. The Spectrashield did not allow the fragments to enter the vehicle.

CONCLUSIONS

Conclusions	3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel backed with 4.9 kg/m2 (1.0 psf) Spectrashield can prevent the penetration of the shrapnel created by a pipe bomb filled with 454 g (16 oz.) of smokeless powder detonated 305 mm (12 in.) from the armour.

RECOMMENDATIONS

Recommendations	3 mm (1/8 in.) of Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 in.) of Jessop 529 steel backed with 4.9 kg/m2 (1.0 psf) Spectrashield can be used to prevent the penetration of the shrapnel created by a pipe bomb filled with 454 g (16 oz.) of smokeless powder detonated 305 mm (12 in.) from the armour.

TEST IDENTIFIERS

Test Series	4
Site	Val des Monts
Date	98-07-11

PROCEDURE

Objective	To determine if 3 mm (1/8 inch) Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 inch) of Jessop 529 steel can defeat a pipe bomb placed in contact.
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 ounces)
Charge Name	Red Dot smokeless powder
Charge Manufacturer	
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	Contact
Charge Location	Roof
Vehicle	Test Fixture
Armour Systems	
A-Armour Location 1	Roof
A-OEM Layer	1 mm (0.04 inches) mild steel
A-Outer Layer 1	3 mm (1/8 inch) Sanderson Keyser Bulloy 500 steel
A-Bonder/Gap 1	Urethane
A-Layer 2	3 mm (1/8 inch) of Jessop 529 steel
A-Bonder/ Gap 2	
A-Layer 3	
A-Witness Panel	1 mm (0.04 inches) aluminum
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	
B-Witness Panel	

Procedure Notes	Pipe bomb placed directly on sheet steel over the center of the test panel (12 mm (0.5 inch) gap between sheet steel and armour). Pipe facing front to back on vehicle with detonator at the front. The outer layer of steel was bolted directly to the test fixture using washers welded to the steel (over holes in the armour). The inner armour was continously welded around the edges to the outer armour with the exception of cut-outs where the bolts passed through the armour.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	Roof
C-OEM Layer	Removed in area of pipe bomb
C-Outer Layer 1	Depressed but intact
C-Bonder/Gap 1	
C-Layer 2	Depressed but intact
C-Bonder/ Gap 2	
C-Layer 3	
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	

High Speed Film	
High Speed Video	
Observation Notes	The two layers of armour were depressed but not cracked or penetrated. The inner layer of armour was depressed 63 mm (2.5 inches).

CONCLUSIONS

Conclusions	The combination of 3 mm (1/8 inch) Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 inch) of Jessop 529 steel can defeat a pipe bomb placed in contact when the layers of steel are continuous.

RECOMMENDATIONS

Recommendations	The combination of 3 mm (1/8 inch) Sanderson Keyser Bulloy 500 steel bonded with urethane to 3 mm (1/8 inch) of Jessop 529 steel can be used to defeat pipe bombs filled with 454 g (16 oz.) of smokeless powder when detonated in contact.

TEST IDENTIFIERS

Test Series	4
Site	Val des Monts
Date	98-08-26

PROCEDURE

Objective	To determine if the application of ceramic armour to the exterior of the door armour system would degrade the armour system's ability to withstand attack from explosive charges, particulary the pipe bomb.
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 oz.)
Charge Name	Smokeless powder
Charge Manufacturer	Hercules Bullseye
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	Contact
Charge Location	Door
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	1 mm (0.04 inches) mild steel
A-Outer Layer 1	3mm (1/8 inch) Sanderson Keyser Bulloy 500
A-Bonder/Gap 1	Urethane
A-Layer 2	3mm (1/8 inch) Sanderson Keyser MVEE Class 2
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	Black cloth
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	
B-Witness Panel	

Procedure Notes	Ceramic panel was composed of outer layer of 1 mm (0.04 in.) cold rolled steel, middle layer of 7.7 mm (0.30 inches) of ceramic and inner layer of layer of 1 mm (0.04 in.) cold rolled steel. A hole was cut in the OEM sheet steel, the ceramic panel was placed on the exterior of the door and the pipe bomb was placed in direct contact (in the center of the lower half of the door). NOTE: This door had been previously tested with the same charge and with small arms fire - test no. 3D1.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	
C-OEM Layer	Completely removed
C-Outer Layer 1	Cracked but not penetrated
C-Bonder/Gap 1	
C-Layer 2	No access to observe
C-Bonder/ Gap 2	
C-Layer 3	Intact
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	

High Speed Film	
High Speed Video	
Observation Notes	The ceramic armour package was heavily damaged and broken up. However, the fragmentation from the ceramic armour did not pose a threat to the steel armour package. The outer layer of the steel armour package cracked in a ""Z"" shape but maintained its structural integrity."

CONCLUSIONS

Conclusions	The application of a ceramic armour package to the base armour did not degrade the protection offered by the base armour when faced with a pipe bomb detonated in contacct.

RECOMMENDATIONS

Recommendations	Ceramic applique armour packages can be used to enhance the ballisitic capability of the base armour package without fear of degrading the explosive resistance.

TEST IDENTIFIERS

Test Series	5
Site	Val des Monts
Date	98-01-22

PROCEDURE

Objective	To determine if 3 mm (1/8 in.) of Compass B555 steel, placed against but not bonded to, 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield can be used as an armour system in an automotive door to provide protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder.
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 oz.)
Charge Name	Smokeless powder
Charge Manufacturer	Red Dot
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	Contact
Charge Location	Door
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 in.) of Compass B555 steel
A-Bonder/Gap 1	Nil
A-Layer 2	3 mm (1/8 in.) of Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	Screen
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	

B-Witness Panel	
Procedure Notes	Pipe bomb suspended against the door skin with its axis parallel to the vehicle's axis. Pipe located so that it was adjacent to the centre of the lower half of the door. Detonator inserted in end of pipe closest to the front of the vehicle.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	One-third missing and bottom pulled out
C-Outer Layer 1	Depressed 71 mm (2.8 in.), no penetrations
C-Bonder/Gap 1	
C-Layer 2	No access to observe
C-Bonder/ Gap 2	
C-Layer 3	No penetrations
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	
High Speed Film	
High Speed Video	

Observation Notes	The door skin was badly damaged and pulled out at the bottom. The armour system was intact with a 71 mm (2.8 in.) depression in the centre. The interior of the door was intact but pushed in 15 mm (0.6 in.).

CONCLUSIONS

Conclusions	The combination of 3 mm (1/8 in.) of Compass B555 steel, placed against but not bonded to 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield installed in an automotive door provided protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder.

RECOMMENDATIONS

Recommendations	This system could be employed where protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder is required.

TEST IDENTIFIERS

Test Series	5
Site	Val des Monts
Date	98-01-22

PROCEDURE

Objective	To determine if 3 mm (1/8 in.) of Compass B555 steel, placed against but not bonded to, 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield can be used as an armour system in an automotive door to provide protection against the fragments generated by a steel pipe bomb filled with 454 g (16 oz.) of smokeless powder at a stand-off of 305 mm (12.0 in.).
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 oz.)
Charge Name	Smokeless powder
Charge Manufacturer	Red Dot
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	305 mm (12.0 in.)
Charge Location	Door
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	Nil
A-Outer Layer 1	3 mm (1/8 in.) of Compass B555 steel
A-Bonder/Gap 1	Nil
A-Layer 2	3 mm (1/8 in.) of Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	Screen
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	

B-Layer 3	
B-Witness Panel	
Procedure Notes	This was the same door used in test no. 5-1. It was not repaired or modified after that test with the exception of the removal of the remainder of the door skin. The pipe bomb was suspended from a frame so that its axis was parallel to the vehicle's axis and the bomb was 305 mm (12.0 in.) from the centre of the lower half of the door. The detonator was inserted in the end of the pipe closest to the front of the vehicle.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	
C-Outer Layer 1	Large indentations, some tensile failures
C-Bonder/Gap 1	
C-Layer 2	No penetrations
C-Bonder/ Gap 2	
C-Layer 3	Intact, no penetrations
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	

VHS	
SVHS	
High Speed Film	
High Speed Video	
Observation Notes	There was a pattern of large indentations in the outer layer that appeared to be made by strips of material from the pipe bomb that hit the door ""flat on"" verses ""edge on"". These strips appeared to be from 12 to 25 mm (0.5 to 1.0 in.) wide and 51 tp 203 mm (2.0 to 8.0 in.) long. Some of the indentations were severe enough to cause tensile failures leaving slits 1.6 to 3.2 mm (1/16 to 1/8 in.) wide. There were several areas where the threads from the pipe caps left impressions in the outer layer. The interior of the door was basically unchanged as a result of the test."

CONCLUSIONS

Conclusions	A vehicle occupant would not have been harmed by the effects of the fragments impacting the door.

RECOMMENDATIONS

Recommendations	When protection against the fragments generated by a steel pipe bomb filled with 454 g (16 oz.) of smokeless powder at a stand-off of 305 mm (12.0 in.) is required, the combination of 3 mm (1/8 in.) of Compass B555 steel, placed against but not bonded to, 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield can be used.

TEST IDENTIFIERS

Test Series	5
Site	Val des Monts
Date	98-01-23

PROCEDURE

Objective	To determine if 3 mm (1/8 in.) of Compass B555 steel bonded with polysulphide to 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield can be used as an armour system in an automotive door to provide protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder.
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 oz.)
Charge Name	Smokeless powder
Charge Manufacturer	Red Dot
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	Contact
Charge Location	Door
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	1 mm (0.04 in.) mild steel
A-Outer Layer 1	3 mm (1/8 in.) of Compass B555 steel
A-Bonder/Gap 1	Polysulphide
A-Layer 2	3 mm (1/8 in.) of Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	Screen
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	
B-Layer 3	

B-Witness Panel	
Procedure Notes	Pipe bomb suspended against the door skin with its axis parallel to the vehicle's axis. Pipe located so that it was adjacent to the centre of the lower half of the door. Detonator inserted in end of pipe closest to the front of the vehicle.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	One-third missing, pulled out at bottom
C-Outer Layer 1	Depressed 57 mm (2.2 in.), no cracks
C-Bonder/Gap 1	
C-Layer 2	No access to observe
C-Bonder/ Gap 2	
C-Layer 3	Intact, no penetrations
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	
VHS	
SVHS	
High Speed Film	
High Speed Video	

Observation Notes	The door skin was badly damaged and pulled out at the bottom. The armour system was intact with a 57 mm (2.2 in.) depression in the centre. The interior of the door was intact.

CONCLUSIONS

Conclusions	A vehicle occupant would not have been harmed by any material impacting or penetrating the door.

RECOMMENDATIONS

Recommendations	If protection against a contact detonated steel pipe bomb filled with 454 g (16 oz.) of smokeless powder is required, 3 mm (1/8 in.) of Compass B555 steel bonded with polysulphide to 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield can be used.

TEST IDENTIFIERS

Test Series	5
Site	Val des Monts
Date	98-01-23

PROCEDURE

Objective	To determine if 3 mm (1/8 in.) of Compass B555 steel bonded with polysulphide to 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield can be used as an armour system in an automotive door to provide protection against the fragments generated by a steel pipe bomb filled with 454 g (16 oz.) of smokeless powder at a stand-off of 305 mm (12.0 in.).
Charge Information	
Charge Type	Pipe bomb
Charge Weight	454 g (16 oz.)
Charge Name	Smokeless powder
Charge Manufacturer	Red Dot
Charge Lot	
Pipe Size	51 mm (2.0 in.) diameter steel
Stand Off	305 mm (12.0 in.)
Charge Location	Door
Vehicle	1992 Roadmaster Full
Armour Systems	
A-Armour Location 1	RF Door
A-OEM Layer	Nil
A-Outer Layer 1	3 mm (1/8 in.) of Compass B555 steel
A-Bonder/Gap 1	Polysulphide
A-Layer 2	3 mm (1/8 in.) of Jessop 529 steel
A-Bonder/ Gap 2	Nil
A-Layer 3	4.9 kg/m2 (I.0 psf) Spectrashield
A-Witness Panel	Screen
B-Armour Location 2	
B-O-OEM Layer	
B-Outer Layer 1	
B-Bonder/Gap 1	
B-Layer 2	
B-Bonder/ Gap 2	

B-Layer 3	
B-Witness Panel	
Procedure Notes	This was the same door used in test no. 5-3. It was not repaired or modified after that test with the exception of the removal of the remainder of the door skin. The pipe bomb was suspended from a frame so that its axis was parallel to the vehicle's axis and the bomb was 305 mm (12.0 in.) from the centre of the lower half of the door. The detonator was inserted in the end of the pipe closest to the front of the vehicle.

OBSERVATIONS

Survive	Yes
Electronic Data	
Internal Pressure (psi)	
External Pressure (psi)	
Lateral Acceleration (g)	
Vertical Acceleration (g)	
Armour Samples	
C-Armour Location 1	RF Door
C-OEM Layer	
C-Outer Layer 1	Large indentations, no cracks
C-Bonder/Gap 1	
C-Layer 2	No access to observe
C-Bonder/ Gap 2	
C-Layer 3	Intact, no penetrations
C-Witness Panel	No penetrations
D-Armour Location 2	
D-OEM Layer	
D-Outer Layer 1	
D-Bonder/Gap 1	
D-Layer 2	
D-Bonder/ Gap 2	
D-Layer 3	
D-Witness Panel	
RecordedVisual Data	
High 8mm	
8mm	

VHS	
SVHS	
High Speed Film	
High Speed Video	
Observation Notes	There was a pattern of large indentations in the outer layer that appeared to be made by strips of material from the pipe bomb that hit the door ""flat on"" verses ""edge on"". These strips appeared to be from 12 to 25 mm (0.5 to 1.0 in.) wide and 51 tp 203 mm (2.0 to 8.0 in.) long. The indentations were not severe enough to cause tensile failures or cracking in the outer layer. There were several areas where the threads from the pipe caps left impressions in the outer layer. The interior of the door was basically unchanged as a result of the test."

CONCLUSIONS

Conclusions	This armour system defeated the fragment threat from a steel pipe bomb filled with 454 g (16 oz.) of smokeless powder detonated at a stand-off of 305 mm (12.0 in.).

RECOMMENDATIONS

Recommendations	The combination of 3 mm (1/8 in.) of Compass B555 steel bonded with polysulphide to 3 mm (1/8 in.) of Jessop 529 steel and backed with 4.9 kg/m2 (I.0 psf) Spectrashield can be used as an armour system in an automotive door to provide protection against the fragments generated by a steel pipe bomb filled with 454 g (16 oz.) of smokeless powder at a stand-off of 305 mm (12.0 in.).

CLAIMS

1. A composite armor material comprising an outer ballistic impact resistant layer of a steel material having a Rockwell "C" scale hardness of 47-54, and an inner blast resistant steel layer having a fracture toughness of 3.6-6.5 J/mm and a Rockwell "C" scale hardness of 28-36, the inner and outer layers being bonded together.

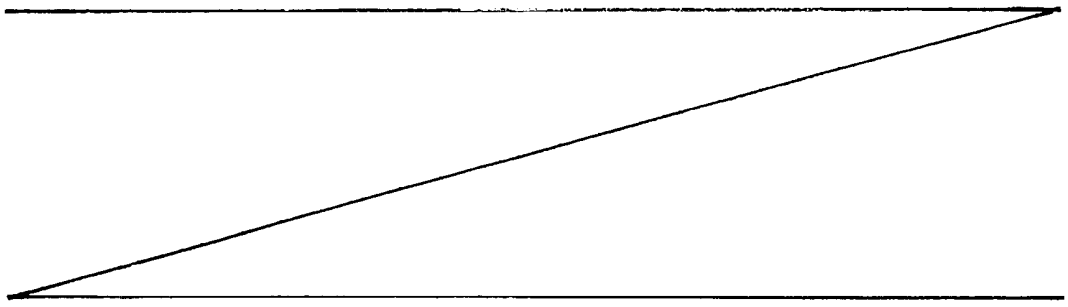
2. A material according to claim 1, wherein the inner and outer layers are bonded together with a synthetic resin bonder between the inner and outer layers.

3. A material according to claim 1, further comprising a layer of a composite of high tensile fibers laminated together with a ductile polymer binder, held in place adjacent to the inner layer by mechanical fasteners, such that in use the material will stretch to trap shrapnel which penetrates the inner layer.

4. A material according to claim 1, further comprising an outermost layer of a ballistic impact resistant steel material having a Rockwell "C" hardness of 47-54, wherein the layers are held together by welding.

5. A material according to claim 1, further comprising an outermost layer of a composite applique material, said applique material comprising two layers of mild steel, sandwiching a middle layer of ceramic tiles bonded in place by an adhesive.

6. A material according to claim 1, wherein the outer ballistic steel layer has a Rockwell "C" scale hardness of 49-51, and the inner impact resistant steel has a Rockwell "C" scale hardness of 28-30 and a fracture toughness of 5.4-6.5 J/mm.



7. A material according to Claim 2, wherein the bonder is a polysulfide-based material having a tensile strength of >1.38 Mpa.

8. A material according to Claim 2, wherein the bonder is a polyurethane-based material having a tensile strength of >6.89 Mpa.

9. A material according to claim 3, wherein the composite is Spectrashield®, having an aerial density of about 4.9 kg/m^2.

Application No: GB 9924501.1 **Examiner:** Emma Tonner
Claims searched: 1-9 **Date of search:** 23 November 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): F3C (CMA, CMB, CP2); B5N

Int Cl (Ed.6): F41H 5/02, 5/04, 7/02, 7/04

Other: Online: WPI, EPODIC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US 4 645 720 (PIRCHER)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.