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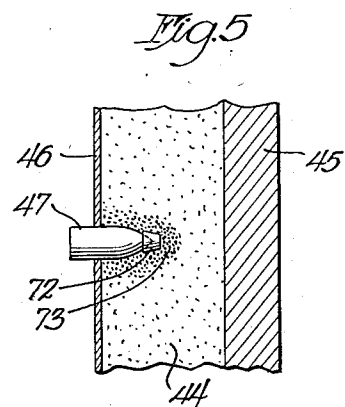
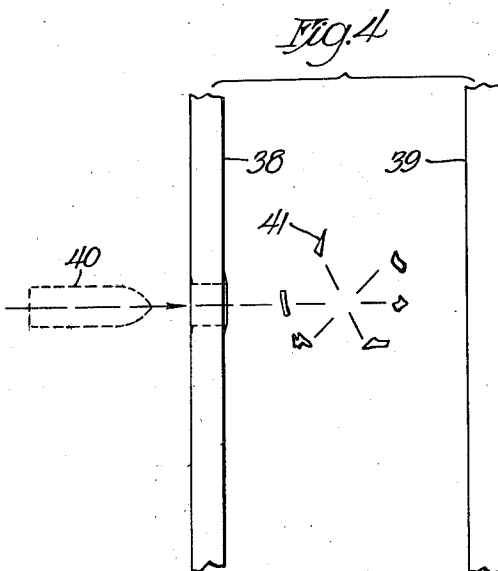
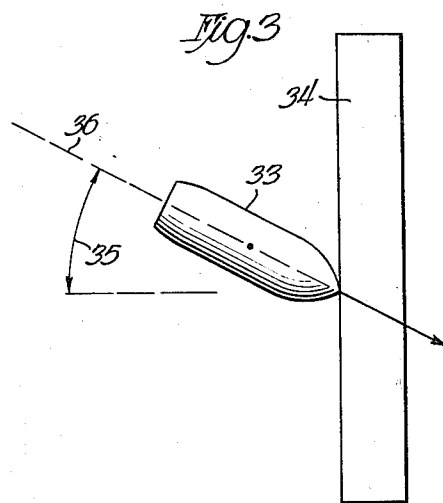
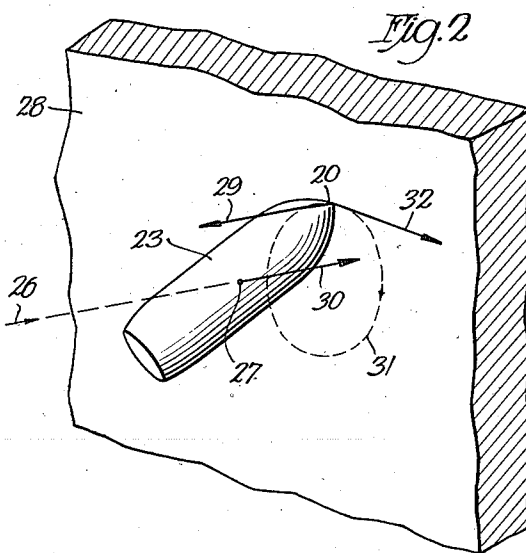
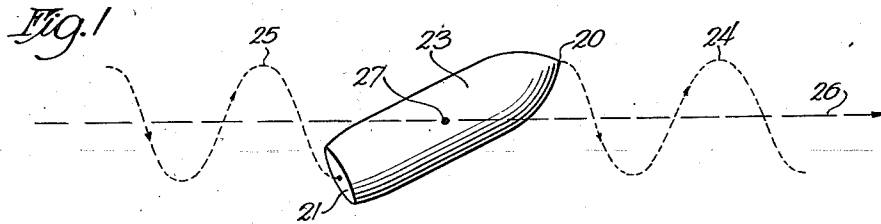
H. W. SHERIDAN

2,391,353

ARMOR

Filed Dec. 4, 1941

2 Sheets-Sheet 1



INVENTOR.

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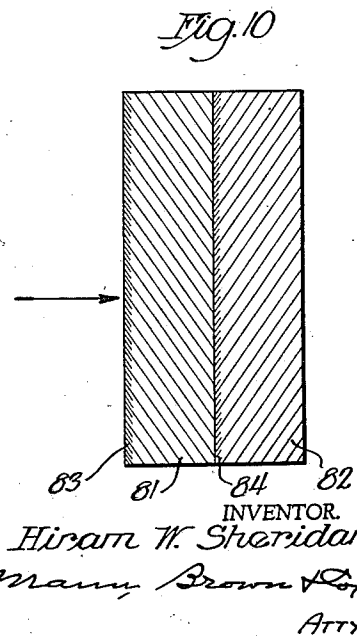
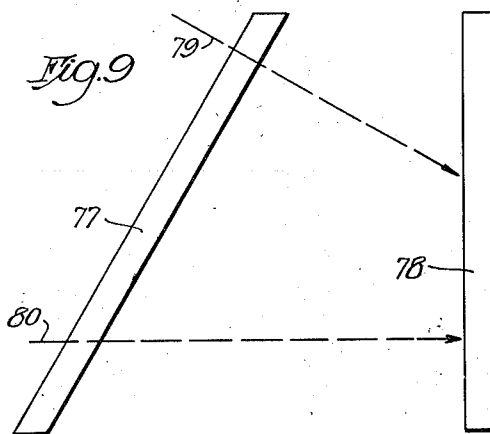
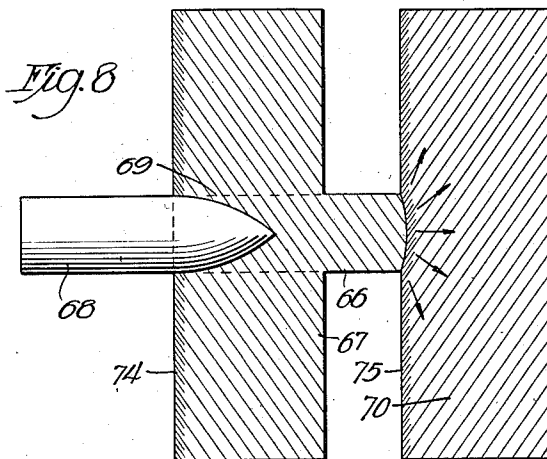
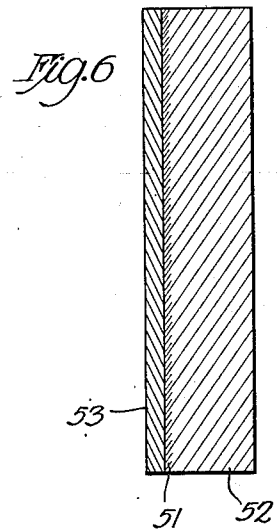
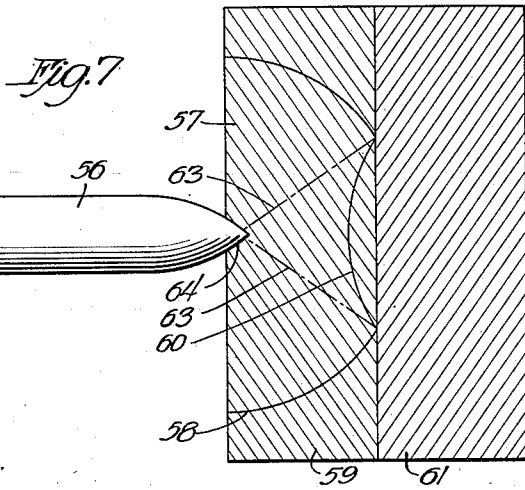
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2 Sheets-Sheet 2



UNITED STATES PATENT OFFICE

2,391,353

ARMOR

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Application December 4, 1941, Serial No. 421,599

6 Claims. (Cl. 109—85)

This invention relates to armor, and particularly to light armor designed to withstand fire from machine guns, rapid fire guns and light artillery, and to be used in airplanes, combat cars, tanks, gun mountings, etc. for the protection of personnel and material. However, armor constructed in accordance with this invention may be made of any desired weight to give protection against guns of any caliber.

The principal object of this invention is to provide armor having a greater resistance to penetration by shell fire in proportion to its weight than the armor known and used at present. With the present types of armor, it is possible to secure protection against the heaviest of armor piercing shells by merely making the armor heavy enough, but, obviously, every increase in the weight of the armor must be paid for by the sacrifice of some other quality. For example, in an airplane, an increase in the weight of the armor can be afforded only by sacrificing some of the load carrying ability, range, or speed of the airplane. It is therefore extremely important to provide armor with the greatest possible resistance to penetration in proportion to its weight.

As the result of research and experiment, I have deduced and discovered the basic physical principles underlying the resistance of armor to the penetration of projectiles. I have also discovered some principles connected with other materials and means whereby a projectile is so affected and influenced that it has much less penetrative ability than it otherwise would have. By utilizing these principles in unique ways, singly and in combination, much better protection can be obtained than with present practice.

These principles and some of the ways in which they can be applied are described below and illustrated in the accompanying drawings, in which

Fig. 1 is a diagram of a shell in flight after striking a small obstruction;

Fig. 2 is a diagram of a shell at an angle to its line of flight striking a sheet of armor;

Fig. 3 is a diagram of a shell striking a sheet of armor at an angle;

Fig. 4 is a diagram illustrating one principle of the invention and a way of carrying that and other principles into practice;

Fig. 5 is a diagram illustrating another principle of the invention and a manner of carrying that and other principles into practice;

Fig. 6 is a section through a plate of armor constructed to carry out another principle of the invention;

Fig. 7 is a diagram illustrating another prin-

ciple of the invention and a construction for carrying that and other principles into practice;

Fig. 8 is a diagram illustrating another principle of the invention and a construction for carrying that and other principles into practice;

Fig. 9 is a diagram of a construction for carrying out several of the principles into practice; and

Fig. 10 is a diagram of another construction for carrying out several of the principles into practice.

My invention may be embodied in practical form in many different ways which carry out various combinations of principles for increasing resistance to penetration. These principles will therefore be explained first.

THE PRINCIPLE OF INCREASING WORK

There is one general principle underlying all protection against projectiles. It is expressed by the work equation. A shell in flight contains a certain amount of kinetic energy. Now, if a projectile is made to do more work than it contains in kinetic energy, it is stopped. Any means that will cause a projectile to do more work than it otherwise would do, adds to protection.

The principle of increasing work is divided into several subsidiary ones.

The principle of tumbling

Projectiles customarily are set spinning by the rifling of guns. When a spinning projectile in flight meets any object, even a relatively very light one, it is caused to tumble. The effect is greater if the object is strong and heavy. The effect is also greater, the greater that the angle is between the vector of the resistance and the axis of the shell.

Tumbling is a word that is used in ordnance to describe the peculiar spiral, or wobble, path that is followed when a shell is upset. A factor is the gyroscopic spin that the projectile possesses. In tumbling, as shown in Fig. 1, both the nose 20 and the tail 21 of the shell 23 describe spiral paths 24 and 25 about the line of flight 26, that is, circular paths relative to the center of mass 27. At no time is the center of mass 27 directly behind the nose 20, so that when the shell 23 strikes a second obstruction, such as a sheet of armor 28, as shown in Fig. 2, it is proceeding somewhat broadside, and the impact further upsets it.

The impact of the shell 23 causes a force 29 to act on its nose 20 in a direction perpendicular to the face of the armor 28, and the inertia of the

shell acts as an equal force 30 in the opposite direction through the center of mass 27. The two forces 29 and 30 form a couple tending to turn the axis of the shell still further from the line of flight 26, and increases the tumbling. Also, the movement of the nose 20 of the shell in a path which is a circle 31 relative to the center of mass 27 of the shell causes it to expend its energy in the direction of the arrow 32 in the plane of the armor plate.

The principle of precession

Tumbling is partly a gyroscopic precession. When precession of a gyroscope is interfered with, the plane of the spin is changed in a direction at right angles to the plane of precession. In a shell, this means that the angle that the shell axis makes with its line of flight, is further increased. In short, the spin of the shell, which was designed to hold its axis in its line of flight, now acts to make it go broadside. This principle is an additional reason why a tumbling shell penetrates poorly.

The principle of non-perpendicular angle of impact

A shell penetrates best when it strikes armor at a perpendicular to the armor, that is, at zero angle of incidence. When a shell 33 strikes a plate of armor 34 at a considerable angle of incidence, as shown in Fig. 3, penetration is greatly reduced. Some of the reasons are set down below.

The greater the angle of incidence 35, the more metal will be in the line of flight 36 to oppose the shell. The greater the angle of incidence 35, the greater the turning couple acting upon the projectile, tending to cause it to glance off. This also results in tumbling and precession, whereupon the nose of the shell is circling with all the energy of the gyroscopic spin; this vector is perpendicular to the ordinary penetration path of the shell, but approximately parallel to the plane in which the armor 34 lies, so that the shell 33 expends some of its energy in the direction that the armor can best resist.

The principle of the fuse effect

Percussion fuses are set to explode at varying intervals after impact.

A good example is the 37 mm. shell used by ground and airborne guns against airplanes. Some fuses are made or set to burst almost instantly upon impact, some to burst some little time after impact. If it is desired to destroy a wing, the shell must burst quickly, else it will burst beyond the wing with little damage. If it is desired to penetrate one or more layers of armor, and then have the burst occur at the point where it will do the most damage to vital elements, the fuse must be set for more or less delay. In particular, if it is desired to penetrate two layers of armor, and then have the burst at the best point, a delayed fuse setting must be used.

If two sheets of armor 38 and 39 are placed, as shown in Fig. 4, so that there is a space between them, the space being filled with air or with some special material, the first sheet 38 met by the shell 40 will set the percussion fuse operating. If the shell 40 bursts immediately, the second sheet 39 will easily stop the fragments 41, and no serious damage will ensue either from the fragments, the pressure wave or from the flame.

A delayed fuse may be used instead of the instantaneous one noted above. If the fuse were properly timed and if the shell had sufficient

energy, it is possible that the shell could penetrate both or all sheets of armor 38 and 39, and then burst at the point of greatest damage.

The result is that the people doing the firing are forced to make a choice, and whatever choice they make forces them to give up one or the other of two classifications of damage. If they choose an instantaneous fuse, their fire will be ineffective against two or more layers of spaced armor. If they choose a delay fuse so timed that the burst will occur at the desired point after passing through two sheets of spaced armor, their fire against thin structures, such as wings, will be ineffective. Against single-sheet armored tanks, too, full delay fuses would burst beyond the point of maximum effect.

The net result of spaced armor is to reduce the over-all effectiveness of fire.

The principle of heat lubrication

A projectile is greatly aided in its journey through armor by producing its own lubrication, and research has shown that this lubrication is a very important factor, indeed.

When a shell pierces armor, a lubricating film is produced. The film consists of some layers of metal molecules of the shell, and of some layers of metal molecules of the armor, which are melted by the great heat which is produced by impact and friction.

The principle of lubricating layers is difficult to study by observation of the impact of a shell on armor, because the action occupies so little time, although considerable information can be deduced by microscopic inspection of the metal concerned after the action is over. I have added to this information by a study of the action of cutting and grinding wheels on sheets of metal. The results of this study are surprising, and very important in the field of protection by armor.

Certain conclusions can be made with considerable confidence. Anything that will scrape away or grind away the lubricating layers created by the shell, will greatly interfere with penetration by forcing the shell to do more work. For example, as shown in Fig. 5, a layer of abrasive crystals 44, such as crystals of Carborundum may be placed in front of the armor 45 and held in place by a retaining sheet 46. When this assembly is struck by a shell 47, the shell will penetrate through the retaining sheet 46 into the layer of abrasive crystals 44, and several effects will occur.

One action is to cool both the shell and the armor where they are in contact, by carrying away the hot, liquid metal. Then, in order to create more lubricating film, more heat must be developed, and so on, the two actions being concurrent. In the temperature range we are considering, the cooler the crystals are, the stronger they are and the more they resist.

Another action is to carry away the lubricating film, thus increasing friction. Still another effect is softening of the nose of the shell, an action which will be explained in greater detail under another principle. Another effect is destruction of the metal of the shell, tending to remove the nose cap of the shell, and to soften and to remove the case hardened point of the shell. All of these effects will occur as a result of any means used to scrape or grind away the liquefied metal.

The principle of heating

The more heat that a shell can be forced to produce, the more energy is used up, and the more work the shell is forced to do. The problem

is that of forcing the shell to produce more heat per unit of distance in penetration, than it otherwise would.

Anything, such as the abrasive crystals 44 shown in Fig. 5, that will not melt to form a lubricating layer, will create more friction than armor metal. Likewise, anything that will melt only at a higher temperature than armor metal, will create more friction than armor metal. The greater the rate of heat production, the greater will be the resistance to penetration.

The principle of preheating the shell nose

It is a principle of physics that of two materials, the harder scratches the softer. This is true even when both materials are very hard. In ordnance, there is a race between the shell points and the armor surfaces in respect to hardness.

While some steels are quite hard at temperatures even including red heat, with a given alloy steel, the hotter it is, the softer it is. If the nose of a shell can be heated, as by the action of the abrasive crystals 44 shown in Fig. 5, even though only the surface layers of molecules are affected, before the point reaches the hardened surface of the armor 45, the point of the shell will be softer than the surface of the armor at the moment of impact. Since the point of the shell is hotter than the surface of the armor at the instant of contact, it will tend to maintain its heat lead throughout the process of penetration. The point will tend to be softer than the armor at the instant of contact, and, in addition, it will tend to remain softer than the armor all the way.

The point of the shell, being softer than the armor face, will flatten upon impact. It will have lessened ability to maintain its shape throughout penetration. Unit area pressure is thus reduced, and the shell is forced to perform more work for each unit of distance in penetration.

The principle of lowered unit area pressure

The sharper a point, the better it penetrates. This is because the pressure is concentrated upon an extremely small area; in other words, the unit area pressure is high. Anything that will lessen the unit area pressure, will lessen penetration.

There are many ways of taking advantage of this important principle. Currently, face hardening of armor plate serves this principle.

The principle of the armor face cap

Armor piercing shells have nose caps. The caps are made of softer steel than the hard points of the shells.

In their text books and in their papers of instruction, our army and navy state that the nose cap has two functions. One function is to fracture the hardened face of the armor before the point arrives. A study that I have made tends to cast some doubt upon the reality of this function, although its reality is of little consequence in connection with the principle here examined. The other function is to support the nose of the shell at impact. The nose is made as hard as practicable, and it is therefore relatively brittle. It tends to splinter. One of the two functions of face hardening of armor is to promote this splintering. The nose cap reduces splintering greatly, and is very effective.

The effect of splintering, one effect, is to reduce unit area pressure.

The hardened face of armor tends to fail by vitreous type of fracture upon impact of the hardened point of the shell, if not of the nose

cap. The point of the shell is supported by its nose cap, but the hard face of the armor is not.

The hardened face of the armor can be given support just as the point of the shell is given support. One way to do this is by essentially the same means that is used for the shell. As shown in Fig. 6, the hardened face 51 of the armor 52 can be overlaid by a sheet of tough metal 53 that is not subject to fracture or splintering. The face 51 of the armor 52 would then be supported quite as the nose of the shell is supported. The great effectiveness of nose caps on shells is a matter of record. Since the physical action is identical, the effectiveness of face caps for armor should be just as great.

The principle of shock waves and reflection

Impact sets up two strains in armor. One is the strain from ordinary pressure, such as a punch causes in a metal plate as it punches a hole through it. When the strain becomes great enough, the adhesion of the crystals of the armor is overcome.

The other strain is the result of a shock wave. Such a wave can be likened to a sound wave in air. Through the comparatively rigid metal of the armor, this wave travels very fast; it is quite short in amplitude and therefore very high in peak pressures. The inertia of the crystals at such high wave speeds is very great, adding to the intra-crystal pressures.

Shock waves tend to break a crystal apart. Also they tend to force one crystal away from another, reducing cohesion. The metal is left in a weakened condition by the passage of an intense shock wave.

When a shock wave arrives at the back surface of a plate of armor, a peculiar action takes place. If there is any roughness on this surface, even a very small roughness that is any greater than that of a mirror-polished surface, minute cracks in the metal occur, and these cracks, starting exactly on the rear surface, radiate backward toward front face of the plate.

In order to eliminate or to lessen the cracking of the rear surface of armor plate, it is the current practice to choose a metal for the main body of the armor that is very tough, but tough metals tend to be soft and rather easily penetrated. The rear surface of all armor should not only be ground and honed, but it should be "super-finished" to a mirror polish. The polished surface should then be protected by a suitable coating against deterioration.

When a shell 56 strikes a plate of armor 57, as shown in Fig. 7, it causes a shock wave 58 to radiate out from the point of impact. When the shock wave 58 arrives at the back surface 59 of the plate 57, it is reflected, as at 60. This is true no matter what lies against this surface, be it air, water, abrasive granules, or another plate of metal 61, hard or soft. Indeed, all waves are reflected at surfaces.

The initial shock wave 58, then, is confined to the first sheet of armor 57, with one exception of small magnitude. If the second sheet of armor 61 should be placed against the rear surface of the first sheet and bonded there so that the bond is very close in a molecular sense, and if the second sheet 61 has about the same index of refraction as the first sheet 57, some of the initial shock wave will be transmitted into the second sheet. Ordinarily the reflection is complete, and the shock wave 58 is entirely confined to the first

sheet. Therefore, the shock wave does not weaken the second sheet of armor.

As stated before, ordinary strain lines 63 are generated in the metal of the armor by impact, due to pressure. These strain lines radiate from the point 64 of the shell. They may be studied in transparent plastic models by means of polarized light.

The initial shock wave 58 travels much too fast to add to the effect of pressure strains. The reflected shock wave 60, however, is a different matter.

When a reflected shock wave strain 60 meets a pressure strain 63, the effect may be subtractive or it may be additive. Where the two types of strain add, disruption of the metal is greatly facilitated. It is, then, very important to get rid of the shock wave 58 as quickly as possible, or to confine it as much as possible to the smallest amount of armor metal. In other words, it should be confined as near to the face of the first sheet of armor as is possible. This is also true, of course, with respect to the pressure strains.

The principle of strain line termination

When a stress is applied to a rigid material, strain lines appear. It is along such strain lines that many structural failures occur. Strain lines change their direction at a surface. They are transmitted very little through a surface unless the bond at the surface with the adjacent material is very close.

Pressure strains can cause cracks on the rear surface of armor plate just as described above in the case of shock wave strains, and the same corrective expedient should be used.

As in the case of shock wave strains, pressure strains should be confined to as small a depth behind the face of the first sheet of armor as possible. The word "first" is here used in the sense of being the first to be met by the shell. In the arrangement shown in Fig. 7 the strain lines 63 are forced to terminate a short distance in back of the face of the armor by dividing the armor into two layers 57 and 61.

The principle of the plug

Impact causes failure in armor. Each failure, for purposes of study and corrective action, can be analyzed into several elements as to the structure and as to the precise action causing each of them to appear in the structure.

It is well known that, as shown in Fig. 8, a plug 66 of metal is punched out of an armor plate 67 by an impinging shell 68. The caliber of the plug 66 is about the caliber of the shell 68 that punches it out. The action here is not unlike that of a punch press. It is plain that there is a stress in shear, and that this stress is concentrated on a cylindrical surface 69 in the armor.

The plug 66, in the germinating stage or after the plug has created slipping surfaces or during both, can be made to distribute and disperse the force that is applied through it, by placing a second plate of armor 70 behind the first plate 67. Doing this, unit area pressure is reduced, and the projectile is forced to do more work per unit distance of penetration.

Application of principles

The practical application of the principles of armor protection, explained above, requires a close study of the requirements of each vehicle and of each unit that is to receive the protective armor. Compromises must be made; thus, air-

plane armor must be reconciled with a demand for light weight. A certain protective arrangement may, and usually will, be so designed as to take advantage of two or more of the principles of armor protection. The variety of the combinations of armor elements and of armor principles that is possible, is rather extensive.

Some of the constructions which have been illustrated to explain the principles are also good ways of applying those principles. The construction illustrated in Fig. 4, for example, is a practical application of many of these principles and acts as follows:

1. The shell 40 strikes the first sheet of armor 38.
 2. The nose cap of the shell 40 is destroyed.
 3. The shock wave is confined to the first sheet 38.
 4. Pressure strain is confined to the first sheet 38.
 5. The percussion fuse is set in operation.
 6. The shell 40 may penetrate the first sheet 38.
 7. The shell 40 is set tumbling; it precesses.
 8. The nose of the shell is heated by the first sheet.
 9. The plug, punched out of the first sheet, precedes the shell to the second sheet.
 10. If the shell has a quick acting fuse, it will burst in the air space between the two sheets of armor.
 11. If the shell has a slow acting fuse, slower than the current practice, the shell may reach the second sheet of armor.
 12. The plug, having preceded the shell, sets up a turning couple in the shell, tending to turn it broadside.
 13. The plug interferes with shock wave formation in the second sheet.
 14. The plug distributes and disperses pressure strains.
 15. The plug lowers unit area pressure.
 16. The shell meets the hardened face of the second sheet of armor 39, without the protection of its nose cap, which was destroyed by the first sheet 38. The nose of the shell tends to splinter. Thus the shell has no more penetrative power than did the old, unsatisfactory, uncapped shells.
 17. The nose of the shell has been heated by the first sheet of armor, and it is therefore softer than it was at impact upon the first sheet. The point of the shell is flattened to some extent, lowering unit area pressure.
 18. Since the shell is tumbling, the shell axis is not coincident with the line of flight. The shell is presented somewhat broadside so that much more metal of the shell is presented to the second sheet of armor than otherwise would be the case, lowering unit area pressure. A turning moment or couple is created which causes the shell to go still more broadside.
 19. Because the angle of reflection is equal to the angle of incidence, the shell tends to glance off.
 20. The shell is precessing so that some of its energy is directed in the plane of the second sheet; thus there is left less energy for penetration.
- In the construction shown in Fig. 4, the air space between the two sheets of armor 38 and 39 will vary according to the demands of the situation. Intrinsically, the greater the air space, the better the action. It is probable that fixed fortifications will use very wide spacing. Large tanks may use a fairly wide spacing, with a marked improvement in the weight-protection ratio.

Small tanks may utilize rather closely spaced armor sheets around the outside of the tank, while vital spots on the inside, such as the men, may be protected with still another light sheet of armor in the airplane style.

The sheets of armor 38 and 39 need not be parallel. The space between them need not be filled with air. Different constructions will be described in the following sections of this paper.

Holes in the sheets of armor must be avoided if at all possible. This is particularly true of the first sheet. Rivet holes, holes for bolts, and taps for screws, are points of great weakness. A direct hit upon a rivet has been found to be very serious. Where possible, the sheets should be fastened to each other and to the vehicle by means of lugs, nubs, dogs or other protuberances integral with the sheets, by welding or otherwise, so that as many holes as possible may be avoided. This consideration applies to all armor.

Another practical application of many of the principles explained above is the construction shown in Fig. 5, in which a sheet of armor 45 is preceded by a layer of abrasive granules 44 which are held in place by a retaining sheet 46 of metal or of other material. This construction acts as follows:

1. The shell 47 meets the retaining sheet 46 and pierces it.

2. The shell is set tumbling and precessing.

3. Precession is interfered with by the granules 44. Therefore, the axis of the shell 47 is forced to a greater inclination by gyroscopic forces.

4. As a result of tumbling, precession, and increasing the angle of the axis, part of the energy of the shell is dissipated laterally in the layer of granules 44.

5. The fuse is set in operation upon impact with the retaining wall, and if it is a quick fuse, the shell may burst in the layer of granules 44, preventing penetration of the armor 45.

6. The nose cap 72 is stripped off the shell partly by the action of the retaining wall. Friction on the abrasive granules 44 is intense, surface layers of molecules are liquefied, and then brushed away by the granules so that there is no lubricating layer formed.

7. The granules 44 also grind away the metal of the nose cap 72.

8. When the nose cap 72 is gone, the action of 6 and 7 above takes place upon the point and nose of the shell 47 itself. The point is blunted.

9. Pressure stresses are distributed radially into the layer of granules 44 and thus concentrated stresses upon the armor 45 cannot arise at this point in the action.

10. The initial shock wave is absorbed in the granules 44.

11. The granules pack tightly about the nose of the shell. In effect, the shell no longer has a point. This fact is of great importance both during progress through the granules and upon contact with the armor plate 45. Motion through the granule layer 44 is greatly impeded by the nose pack 73 which lowers unit area pressure and causes the shell to affect a larger and larger number of granules in order to make progress.

12. The abrasive granules 44 are designed to give the greatest possible friction so that the energy in the shell is very quickly used up. This is especially true since lubricating layers cannot form.

13. The granules protect the hardened face of the armor plate 45 against vitreous fracture,

should the shell 47 continue far enough to make an energetic impact upon it.

14. The nose pack 73 distributes the area of impact. This protects against vitreous fracture.

15. The nose pack 73 lessens the unit area pressure upon impact. By increasing the time of impact, the nose pack 73 also tends to soften the impact, giving a sort of inelastic effect, or, in a sense, a gradual effect of impact.

16. The nose pack 73 distributes pressure stresses.

17. The nose pack greatly reduces shock wave formation upon impact with the armor face.

18. By passage through the retaining wall 46 and especially by passage through the layer of granules 44, the nose of the shell 47 has been heated. It is true that heat is transmitted slowly through the metal of the shell, slowly as compared with time of impact and partial penetration, and it may be true that heat has not time enough to go very deeply into the material of the shell. However, a study of armor plate and of shell fragments after impact, indicates that the effect of heating during impact on current armor is of the utmost importance in regard to the physical action of penetration.

Either the intense heat goes deeper into the metal than our equations would lead us to believe, or else only the surface layer of molecules is heated, which is brushed or ground away, presenting new surface layers, one after the other, with great rapidity. An examination of punctured armor shows large amounts of metal that has flowed, metal that had evidently been liquefied. Examination of the crystals shows the effects of heat at some depth.

Nevertheless, whichever action takes place, or whatever the combination of the two actions, makes no difference in the consideration here examined. The nose of the shell, surface or in depth, has been heated. The nose, surface or in depth, is softer than it otherwise would be. It is thus softer than the hardened face of the armor which is cold until impact.

Upon impact with the armor plate, the weaker crystals give way before the harder crystals. The nose of the shell is further blunted, lowering unit area pressure.

The heat lead that the shell has taken from the granules is retained throughout whatever penetration of the armor may take place.

19. Whatever granules are carried by the shell into the armor will increase friction and also will tend to grind away the metal of the shell, at the same time reducing the lubricating effect of the liquid metal layers that are formed.

In the construction shown in Fig. 5, the abrasive granules 44 used will be of the hardest possible material and very heat resistant. Silicon carbide can be used, or Carborundum, corundum, emery powder, or even sand, for cheapness.

The size of the granules 44 will be dictated by the effect desired, and may be fine, coarse, or mixed, and they may be retained in place against the armor, loosely, under moderate pressure, or under high pressure. If found desirable, the granules may be imbedded in a hard or a soft plastic, or in a rubber-like material, or any other carrier. If the granules are loose, so that the layer of granules would drain out of a shell hole, a cellular retaining structure may be provided.

The retaining sheet 46 may be made of any suitable material, probably of steel. It may be a sheet of armor itself, with a hardened face.

It is possible, but not likely, that abrasive granules may be incorporated in the metal of the armor itself. Among the purposes would be to increase friction during holing, and to eliminate the lubricating action of liquefied metal layers.

The dimensions of all of the elements may be varied according to the requirements of the situation.

Another practical application of many of the principles explained above is the construction shown in Fig. 6, in which a plate of armor 52 has a hardened face 51, and, in front of the hardened face is a layer of tough steel 53, called the face cap, in close contact with the hardened face.

This construction acts as follows:

1. At the moment of impact, a shock wave is started in the face cap 53.

2. A good part of the shock wave is reflected from the face hardened layer 51, so that a significant amount of the shock wave is confined to the tough face cap 53, thereby protecting the hardened face 51 against fracture.

3. The face cap 53 begins to destroy the nose cap of the shell by pushing it backward on the shell body, which tends to break the close cohesion of the nose cap with the nose, thus decreasing support from the nose cap.

4. The point impinges upon the face hardened surface 51 of the main armor plate 52. The shell has been slightly slowed by the face cap 53. The impact upon the hard face 51 is somewhat cushioned by the face cap 53.

5. The face cap 53 now supports the hard face 51 against vitreous fracture, splintering, and other types of fracture. The face cap 53 now does as much for the armor 52 as the nose cap did for the shell when the latter was adopted. For the reason of the support given by the face cap, the hard face 51 can be made very much more hard than is the current practice, thus greatly increasing resistance to penetration.

At present, armor is made with a face as hard as can be done without sacrificing too much to brittleness. It would be very desirable to make it much harder, but if this is done, it would be brittle and fracture easily. The face cap 53 now allows the face 51 to be made much harder, with all the gain that means in resistance to penetration by projectiles.

In the construction shown in Fig. 6, the face cap 53 should be made of a tough steel, like the nose cap of the shell. It should be placed in contact with the face 51 in the same manner that the nose cap is placed in contact with the metal of the shell body, to give the maximum of support against fracture.

The thickness of the face cap 53 can be adjusted to the demands of the situation. Where weight is a major consideration, as in airplanes, the face cap 53 can be made fairly thin. A very thin face cap, if the bond is good, and if the metal is tough, will afford a surprising amount of protection against fracture.

Another practical application of many of the principles explained above is the construction shown in Fig. 7, which shows schematically, strain line termination at a margin or surface. The construction is the simplest that will give the effect.

This construction acts as follows:

1. The shell 56 strikes the first layer of armor 57. A shock wave 58 is started. Pressure strains 63 are created.

2. The shock wave proceeds to the margin 59, and is reflected, as at 60. The reflection is complete if the bond between the two plates is not close. The shock wave 58 is, on the whole, confined to the first plate, so that it does not contribute to a break-down of the crystals of the second plate 61.

3. The pressure strains 63 do not pass the margin 59 into the second plate 61. A plug that may be sheared out of the first plate cannot cause sharp shear strains in the second plate.

In carrying out in practice, the construction shown in Fig. 7, it is probable that two armor plates 57 and 61 placed against each other, with only the face of the first plate 57 hardened, will seldom be used. It is probable that, at least, the face of the second plate 61 will also be hardened. Variations such as a space between the plates filled with air or abrasive granules, a face cap or a layer of granules plus a face cap, and many others may be used to satisfy a given situation.

Another practical application of many of the principles explained above is the construction shown in Fig. 8, in which the two sheets of armor 67 and 70 are spaced apart and are provided with hardened faces 74 and 75. In this construction, many of the actions discussed above take place, and, in addition, the following occurs:

1. The shell 68 makes impact with the first sheet of armor 67. Shear strain is set up, and a plug of metal 66 of about the caliber of the shell, begins to be pushed out. If the armor should be in one sheet, the strain in shear that permits the plug to be formed, will be continuous to the back surface of the armor. In two or more sheets 67 and 70, however, the shear stress terminates at the rear surface of the first sheet of the armor 67.

2. The plug pushes against the face of the second sheet of armor 70. Unit area pressure is quite low. The stress is distributed. No concentrated shear stress can be created.

3. The plug 66 will tend to flatten. Its metal will seek the line of least resistance. No plug can be formed, and none can be pushed out of the rear of the second sheet of armor 70.

4. The plug 66 tends to upset the shell 68.

5. The plug cushions the impact of the shell 68 with the second sheet 70.

6. Since heavy armor is seldom if ever punctured without the formation of a plug, and since double sheet armor greatly interferes with or prevents entirely, the formation of a plug in the rear or second sheet 70, it will be found very difficult to hole armor of the multiple plate type.

In carrying into practice the construction shown in Fig. 8, both sheets of armor 67 and 70 will have hardened faces 74 and 75. Whether they are placed in contact or more or less widely separated, will depend upon the demands of the situation. Many variations and combinations can be made, such as face caps, granules, and the like, to take advantage of as many of the principles of armor protection as possible.

Another practical application of many of the principles explained above is the construction shown in Fig. 9, in which two sheets of armor 77 and 78 are located at an angle to each other instead of being parallel. This construction acts as follows:

1. If the shell strikes the first plate of armor 77 at zero angle of incidence, following the path 79, for example, it strikes the second sheet 78 at a large angle of incidence. If it should strike

the second sheet 78 at zero angle of incidence following the path 80, for example, it will have struck the first sheet 77 at a large angle of incidence.

2. A large angle of incidence greatly reduces the penetrative powers of the shell. There are two reasons for this. One reason is that more metal lies in the line of flight than would be the case with zero angle of incidence. Another reason is the tendency of the shell to glance off, and the turning couple set up that tends to present the shell broadside.

3. The first sheet of armor 77 sets the shell tumbling and precessing. The greater the angle of incidence, the greater is this effect. Tumbling shells penetrate poorly, as previously noted.

4. The precessing nose, upon striking the second sheet 79, has a vector lying parallel to that sheet, leaving less energy for penetration.

5. Fuse effect, as previously noted.

6. Destruction of nose cap on the first sheet 78.

7. Preheating nose of shell.

8. Shock wave reflection.

9. Pressure strain termination in first sheet.

10. The plug effect.

Designing armor structures geometrically so that the greatest possible tumbling and fuse effect can be generated, so that the maximum protection will be provided in the direction from which the most fire is expected, and so that weight and space considerations can be met satisfactorily, will call for a good deal of ingenuity. The shape of such structures will doubtless differ with each different situation and different vehicle.

Another practical application of many of the principles explained above is the construction shown in Fig. 10, in which two armor plates 81 and 82 are both provided with hardened faces 83 and 84. They may be placed against each other, or spaced apart. The drawings show them in contact, but the bond between them is only close enough to permit the first plate 81 to act as a face cap for the second plate 82.

This construction acts as follows:

1. The shell strikes the hard face of the first plate 81.

2. The nose cap on the shell is destroyed by the first plate.

3. The shock wave is reflected in good part from the margin with the second plate 82.

4. Pressure strains tend to terminate at the hard face 84 of the second plate.

5. The nose of the shell is preheated, and softened with respect to the hard face 84 of the second sheet.

6. Impact upon the hard face 84 of the second sheet is cushioned by the body of the first sheet 81.

7. The shell is slowed by the first sheet 81 so that the impact upon the hard face of the second sheet 82 is of a low order, and low order impacts do not cause fractures of hard faces.

8. The nose of the shell, being hot and relatively soft, tends to flatten upon the hard face 84 of the second sheet, greatly lowering unit area pressure, and this effect not only reduces penetrative power, but lessens the possibility of impact fracture of the hard face 84 of the second sheet.

9. The tough body of the first sheet of armor 81 acts as a face cap to support the hard face 84 of the second sheet against fracture. Thus the hard face 84 of the second sheet can be made

much harder and more resistant without possibility of fracture than it can under current practice.

10. The plug that tends to be sheared out of the first sheet 81 tends to flatten upon the superhard face 84 of the second sheet, distributing both the pressure and the shear stresses, preventing the formation of a plug in the second sheet 82. Shear stress is not transmitted through the hard face 84 of the second sheet in sufficient concentration to permit shearing out a plug in that sheet.

In making the construction shown in Fig. 10, holes in the armor should be avoided as much as possible, for the reasons previously noted. The bond between the first and the second sheets 81 and 82 should be only close enough to allow the first sheet 81 to act as a face cap for the second sheet 82.

There will be situations where armor of this kind, without the addition of any other elements will be found to be the best construction practicable. However, other elements can be added.

The principle of two hardened faces can be, and in many cases, should be applied wherever two sheets of armor are used. A face cap for the first sheet may be used in most constructions, with little addition to the weight but great addition to the protection.

Conclusion

I have explained above many principles of physical action in armor protection, and have shown and described some of the more simple constructions that apply one or more of those principles. There are, however, a large number of possible combinations of the simple elements and the simple constructions, according to the multitude of situations demanding armor protection, and to the many compromises that must be made with such considerations as weight, available space, speed of construction, tools that are available, possible expense, and the like. No attempt has been made to illustrate or describe all of these, as they are too numerous, and the skilled designer of armored vehicles can, with the aid of the present disclosure, readily devise the particular structure which best meets the conditions of his particular problem. My invention, therefore, is not limited to the few specific constructions shown but includes all constructions falling within the terms of any one or more of the following claims.

I claim as my invention:

1. An armor defense construction comprising a plate of armor steel having its inner face highly polished for lessening the rupture of the plate when struck by a shell on its outer surface, said inner face being coated for preserving the finish, and a plate of relatively soft tough metal in firm contact with the outer face of said plate for preventing shattering of the latter when said plate is struck by a shell.

2. A defense armor member comprising an armor plate having its inner surface highly polished for reducing fracture of the plate when the outer surface of the same is struck by a shell.

3. A defense armor comprising an armor plate having its inner face superfinished to a mirror polish and having its outer face superhardened, and a plate of tough steel in close contact with, and bonded to, said armor plate on its outer side for protecting the latter against shattering by shell-fire.

4. A defense armor comprising an armor plate

having its outer surface hardened and its inner surface ground and honed to a mirror finish for reducing fracture of the plate when the outer surface is struck by a shell, and a protective coating on said mirror finished surface for preserving the finish.

5. A plate of armor comprising a layer of armor steel and a relatively thin layer of soft tough ferrous metal coating said steel on the side exposed to gunfire, the side of said armor steel op-

posite said coating being superfinished to mirror polish.

6. An arrangement of armor comprising a main armor plate having a tough and ductile body and an integral hardened face, and an auxiliary plate of tough and ductile metal overlying said hardened face on the side exposed to gunfire, the opposite side of said body from said hardened face being superfinished to mirror polish.

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