

March 9, 1965

W. SCHMIDT
METHOD OF HARDENING

3,172,199

Filed Sept. 19, 1962

2 Sheets-Sheet 1

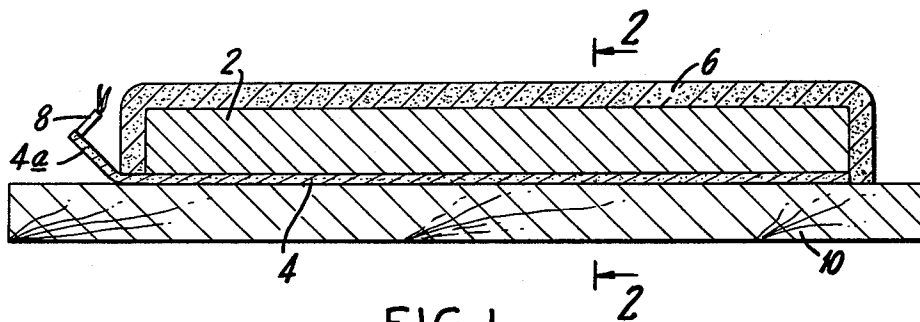


FIG. 1

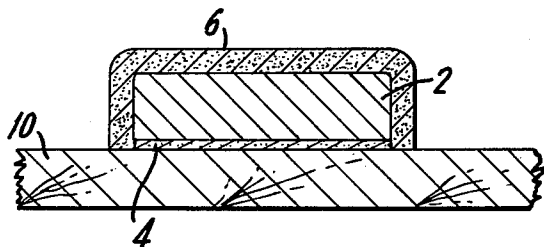


FIG. 2

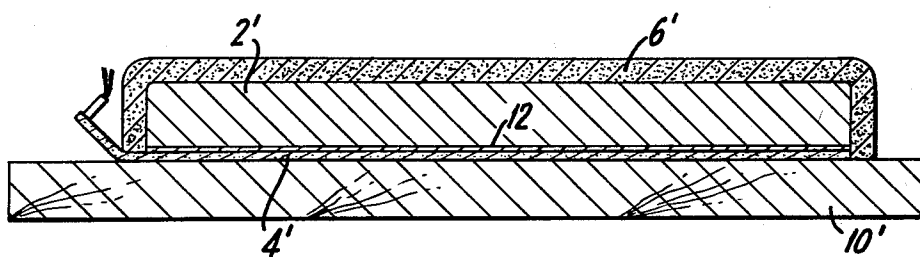


FIG. 3

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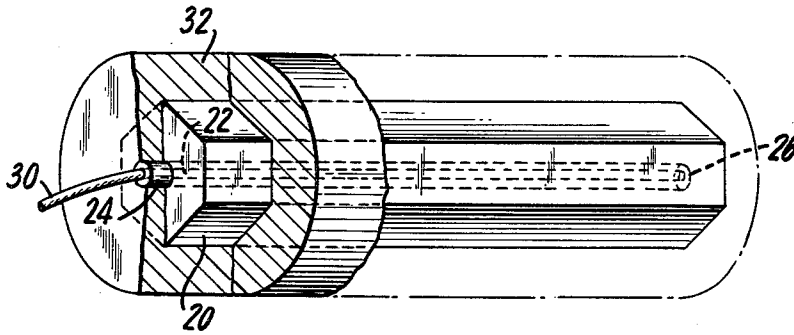


FIG. 4

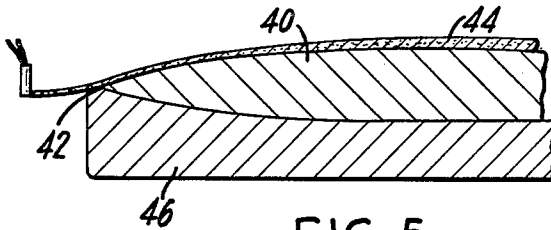


FIG. 5

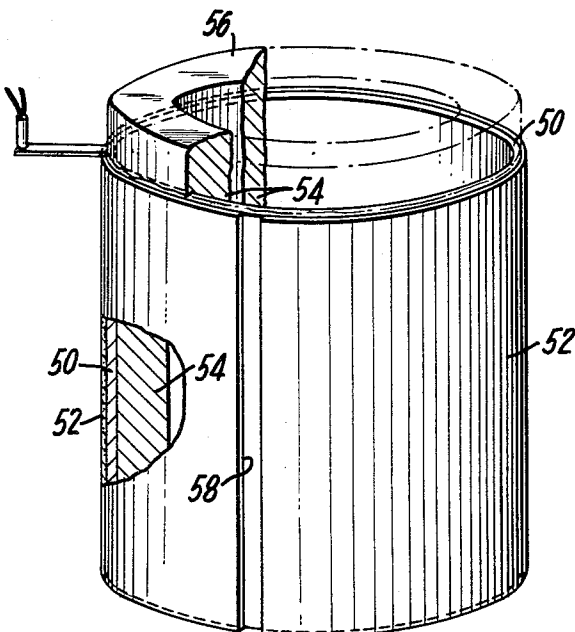


FIG. 6

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3,172,199

METHOD OF HARDENING

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This invention relates to the hardening of metals by the use of explosives, and its object is to provide a method which effectively utilizes both the compressive stresses generated directly by the explosion and the tensile stresses reflected internally from the surface opposite or at inclination to that to which the explosive is contiguous, for hardening the metal depthwise from both surfaces while minimizing fractures from tensile stresses.

It has heretofore been proposed to utilize the compressive stresses generated in metal by an explosive contiguous to one surface to effect hardening of the metal in the zone in depthwise proximity to the surface to which the explosive is contiguous, and it has also been proposed to harden the opposite surface by compressive stresses generated by repercussions from a mandrel of some sort held against the opposite surface.

There are a number of problems which, so far as I am aware, have not been solved prior to the present invention in such proposals for hardening by the use of explosive. Metal has a considerably lower critical tensile strength than its critical compressive strength, with the result that in seeking to utilize compressive stresses which travel through a plate from the blasted surface to another surface tensile stresses are reflected at the other surface, which induce fractures in proximity thereto. Attempts to avoid such fractures have led to the expedient of diminishing the charge to lessen the compressive stresses so they do not reach the other surface in sufficient strength to generate the reflected tensile stresses producing the fractures. But this compromise in the size of the charge leads to compromise in the amount of hardening which may be achieved by such prior methods.

In accordance with the present invention, metal is hardened without fracture by not only utilizing the compressive stresses but by also generating tensile stresses of controlled magnitude less than that which would exceed the critical tensile strength of the material and utilizing these controlled tensile stresses for metal hardening.

By my invention a piece of metal is hardened by detonating in proximity to one of its faces a charge of explosive exceeding that required to transmit compressive stresses through the thickness of the metal to another face and then absorbing, from the compressive stresses so transmitted through the metal, the excess over that which generates a reflected tensile stress approaching the critical tensile strength of the material. The explosive used has a velocity of detonation substantially exceeding the velocity of sound in the metal to be hardened and may be of a magnitude approaching, although less than, that required to reach the critical compressive stress of the metal. The absorption is accomplished by disposing adjacent one or more surfaces of the metal other than the blasted surface a layer of material having a density, a velocity of sound propagation and a specific acoustic resistance of certain values to be described.

In the drawings:

FIG. 1 is a diagrammatic section showing the use of my invention in hardening a steel plate;

FIG. 2 is a vertical section on the line 2—2 of FIG. 1;

FIG. 3 is a view corresponding to FIG. 1 showing a modification;

FIG. 4 is a diagrammatic perspective view of the use of my invention in hardening a drilling rod;

FIG. 5 is a diagrammatic section showing the use of my invention in hardening a pneumatic chisel; and

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FIG. 6 shows the use of my invention in hardening a conveyor tube.

In many metals, especially iron and steel, a tensile stress of given magnitude produces a greater hardening than is produced by a compressive stress of the same magnitude. Where both compressive and tensile stresses are employed to harden, which not only differ in their hardening effects for equal magnitudes of stress but which whether compressive or tensile, vary by decreasing in intensity as the stress does work in hardening the metal during transmission therethrough, there may be marked differences in the hardening effects at different surfaces and at different depths below the various surfaces. In the practical utilization of my invention, I may, by suitable positioning and arrangement of the explosive and absorptive layers during the treatment, direct the greatest stress to the zone requiring the greatest hardening effect, and, in many instances, I have found that the part requiring the greatest hardening should be subjected to a tensile stress of the greatest magnitude below the critical tensile stress.

More specifically, in accordance with my invention, hardening in depthwise proximity to a given surface of metal by the use of tensile stress is achieved by coating that surface with an absorptive layer of desired characteristics and applying the explosive to another surface, opposite or disposed at an inclination to the surface to which the coating is applied. The material of the coating absorbs or conducts away from the metal a portion of the compressive stress reaching the surface to which the coating is applied, with the result that there is reflected back internally of the metal a tensile stress of a magnitude below the critical tensile stress of the metal. The reflected tensile stress may typically be of the order of 75% of the magnitude of the compressive stress reaching the said surface in contrast to a stress of virtually 100% of the delivered compressive stress which would be reflected as tensile stress if there were no such coating, approximately 25% of the compressive stress reaching the surface being conducted away from the metal by the coating material. In this way, I am able to use an explosive charge of a magnitude to produce at the blasted surface compressive stresses approaching the critical compressive stress of the material, with consequent effective hardening by the compressive stress while utilizing, for even greater hardening, if desired, the reflected tensile stresses of controlled high magnitude less than the magnitude of the greatest compressive stress and below the critical tensile strength of the material.

The action of the coating layer in absorbing and conducting away a portion of the compressive stress reaching the surface of the metal which it coats is a function of the specific acoustic resistance of the material:

$$SAR=r \times c$$

where r is the density of the material in g./cu. cm.; c is the velocity of sound in the material in cm./sec.; and SAR is the specific acoustic resistance in g./sq. cm. sec.

For effective stress wave absorption, the coating material should have a density within the range of from about 40% to about 70% and preferably from about 50% to about 60%, of the density of the metal to be hardened; it should have a velocity of sound propagation of from about 15% to about 40% and preferably from about 20% to about 30% of the velocity of sound in the material to be hardened, and the specific acoustic resistance of the material should be within the range of from about 5% to about 30% and preferably from about 10% to about 20%, of the specific acoustic resistance of the material to be hardened.

The density and velocity of sound propagation, from

which the specific acoustic resistance can be calculated by the formula above, are well known for metals or other materials to be hardened or can readily be measured by known techniques, and the same is true of materials to be used for the absorptive coating. Thus, selecting a steel alloy as a typical metal to be hardened, its density is 7.8 g./cu. cm., and the velocity of sound in the metal is 594,360 cm./sec., as are well known, and its specific acoustic resistance is calculated as 4,636,000 g./sq. cm. sec. Many materials are known which with relation to steel have the needed density, velocity of sound propagation and specific acoustic resistance required as a suitable coating material. White lead (basic lead carbonate or hydrocerussite having the formula $\text{PbCO}_3\text{Pb(OH)}_2$) has a density of 4.13 g./cu. cm. (about 53% that of steel), a velocity of sound propagation of 163,900 cm./sec. (about 27% that of steel), and a specific acoustic resistance of 676,900 g./sq. cm. sec. (about 15% that of steel), all within the preferred ranges. Other suitable absorbent materials for use with steel include barium sulfide, BaSO_4 , of 4.50 g./ccm. density; manganese dioxide, MnO_2 , as a powder, of 5 g./ccm. density; ferric oxide, Fe_2O_3 , as a powder, of 5.24 g./ccm. density; aluminum oxide, Al_2O_3 , powder, of 3.97 g./ccm. density.

For ease in handling, the coating material is compounded by the addition of oil or water to the powder to produce a putty-like composition of sufficient plasticity to facilitate its tenacious application to one or more faces of the object being hardened even though of irregular shape such as would be presented, for example, by plow blades, tools, dies, drill rods, and the like. The thickness of the coating may vary widely, but it should be thicker than one-half of the length of the stress wave reaching the surface to which the coating is applied, which in turn will vary with a number of factors, including the thickness of the material being hardened which attenuates the wave during its transmission through the metal. I have found from my experience that this thickness should be not less than $\frac{1}{4}$ inch, twice the wave length in a typical case of a steel plate one inch thick, and need not be more than an inch in thickness.

The explosive, which also may conveniently be in the form of a readily applicable putty-like mass, should have as high a velocity of detonation as possible and well above the velocity of sound in the material being hardened, which in the case of steel is 19,500 ft./sec. Typical of such explosives are pentaerythritol tetranitrate, known as PETN, having a velocity of detonation of about 24,500 ft./sec. In form it is available as a flexible sheet which can be readily cut with a knife to the right size and shape and molded to fit the contour of the article to be hardened. To insure maximum utilization of the detonation pressures, the explosive may also be tightly glued to the surface of the object. Of the various types of PETN explosive available, I have successfully used type EL-506A-4 (density 4.0 g./sq. inch) and with a sheet thickness of 0.165 inch an EL-506A-2 having a density of 2.0 g./sq. inch and a sheet thickness of 0.084 inch.

The thickness of the explosive used varies according to its intensity, the higher the velocity of detonation, the thinner may be the sheet of applied explosive.

In the drawings I have illustrated typical procedures for hardening metal, of various forms, in accordance with my invention.

FIG. 1 shows perhaps the simplest embodiment in which my invention is employed to harden a rectangular metal plate such as might be used for armament in ship-building, armored cars, or other purposes. The plate is illustrated at 2, the explosive at 4, and the absorbent coating at 6. The explosive 4 is in the form of a sheet of predetermined thickness, and its main body portion is of a length and width conforming to the length and width of the steel plate 2. A detonator 8 of conventional type is used, which, for convenience, is connected to a margin

4a of the explosive layer projecting from beneath the metal plate at one end. The explosive sheet 4 is placed on a shock resistant support 10, after which the plate 2 is superimposed on the explosive sheet 4 and the absorbent coating 6 is then applied to cover the top and the four exposed sides of the metal plate. To reduce the noise of the explosion, the entire assembly may be submerged under water. The explosive is then detonated.

Illustrative of the results that may be achieved by my invention, I have hardened a plate of SAE 4160 alloy spring steel with excellent results despite the fact that, in instances, the plate had already been hardened to the extent possible by classical metallurgical methods. In one test I used a sample measuring 11 x 4 x 1 inches. The explosive used was PETN (EL-506A-2) in a sheet .084 inch thick. To insure maximum utilization of the detonation pressures, the explosive sheet was tightly glued to the surface of the steel with rubber cement and kept under mild pressure for several hours. The coating 6 consisted of basic lead carbonate 88%, commercially known as white lead, pure linseed oil 10%, mineral spirits 2%, and had a density of 4.13. It was applied with a coating about one-fourth inch in thickness.

Thereafter, the plate was measured for hardness, in a manner to be described, the results compared with similar measurements on a control piece of the same metal that had not been subjected to my hardening treatment, and the results compared. The hardened piece was also examined microscopically for the presence of micro-fractures.

In this analytical work the hardened plate was first cut into several vertical sections. Hardness measurements were then taken in a manner to obtain comparable figures to establish relative hardness of various selected parts of the exposed vertical surfaces of the sections at various corresponding distances from the blasted wall, and the results at each distance averaged. The measurements were taken on a Rockwell Superficial Hardness Tester using Scale 45-T. The results showed a hardness at the blasted wall of 87.2 as compared with a value of 85.7 for the control. Midway of the section the value was 85 as contrasted with 84.8 for the control, and at the opposite surface to which the coating was applied, the value was 89 as contrasted with 85.7 for the control. It was noted that the hardness in depthwise proximity to both of the opposite surfaces was considerably greater than with the control and that a greater amount of hardness was attained from the tensile stress at the coating surface than from the compressive stress at the blasted surface.

No micro-fractures were observed.

In a further test on a low carbon steel plate measuring 11 x 4 x 1 inches, the hardness ranged from a minimum of 60 to a maximum of 65.5 at various cross-sectional zones in contrast with values of from below 54 upwardly but not exceeding about 59 for the control.

In a further test on a plate of SAE 4160 alloy spring steel, also measuring 11 x 4 inches, but $1\frac{1}{8}$ inches thick, using the same explosive and the same thickness of lead coating, having an average hardness in the control of about 30.5 measured on a C Scale RS, a sample of the steel hardened by my method showed values ranging from about 31 to about 34.7.

FIG. 3 illustrates a modification of my invention especially adapted for the hardening of high-carbon steels. As indicated by the primes of the corresponding references in FIG. 1, the plate 2' is hardened by an explosive 4' supported on the support 10', the plate being covered by coating 6'. With the case of high carbon steels, however, I preferably interpose between the sheet of explosive 4' and the plate 2' a sheet 12 of asbestos or the like typically of the order of $\frac{1}{32}$ of an inch thick. I have found that such a sheet effectively functions as a heat barrier to prevent intimate contact between the

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explosive and the steel, which is effective to absorb some of the heat from the explosion sufficiently to prevent annealing of the blasted surface. In contrast with an average annealing temperature ranging from 900° C. to 700° C. with steel having carbon contents ranging, respectively, from 0.1% to 1.2% PETN explosive has a detonation temperature which, although of very short duration, may be as high as 5,400° C. By the use of this intervening asbestos sheet, I have found that although the shock wave is not diminished appreciably, the temperature to which the blasted surface is subjected is maintained below the annealing temperature, and thus I assure against softening of the blasted wall by annealing.

In FIGS. 4, 5, and 6 I have shown typical examples of the many metal parts which my invention is well adapted to harden. FIG. 4 shows at 20 a mining drilling rod having the conventional bore 22 extending axially throughout the piece and through the screw threaded tip 24 used to attach the drill bit. Typically, the wall thickness of such rods is of the order of 1 inch to 1½ inches. The bore may be ¼ to ½ inch in diameter and leads to the inlet water hole 26, of the same diameter which is highly sensitive to breakage in the ordinary use of such rods. To harden a rod of that character, I would employ an explosive 30 in the form of a primacord extending through the bore 22. Completely surrounding the periphery of the drilling rod is a coating 32, which may comprise white lead and be of the specifications above given. It is applied to a thickness of from ½ to ¾ of an inch. The explosive is suitably detonated and the tensile stresses of magnitude controlled by the coating 32, as well as the compressive stresses, are effective to produce a drilling rod which is of substantially greater hardness than has been known heretofore.

In FIG. 5 I have illustrated at 40 a pneumatic chisel having a sharpened end 42. It would be hardened according to my invention by the combination of an explosive sheet 44 suitably detonated, applied to one surface of the chisel, and a protective coating 46 on the opposite surface.

In FIG. 6 I have shown a tubing 50 of the kind used for conducting stone, coal slurry, ore, and the like, which is hardened to withstand rough usage by wrapping a sheet of explosive 52 about the tubing and coating its inside wall with an absorptive layer 54 and covering its opposite edges with further absorptive layers 56. For such purposes, I select an explosive sheet of a length perhaps ½ inch less than the periphery of the tubing in order that the ends of the explosive sheet do not touch but are spaced by a small gap as indicated at 58 to avoid convergence of generated stress waves traveling in opposite circumferential directions about the tubular body. Alternatively, the hardening may be accomplished by reversing the position of the inner and outer layers, placing the explosive inside and the absorptive layer outside the tube.

I have found that my invention, several embodiments of which have been above described, has substantial advantages over prior known methods of hardening by the use of explosives. It is especially effective for the further hardening of metals which have previously been hardened by conventional metallurgical methods such as shot peening, carburizing, or the like; it does not embrittle the material but leaves it strong and ductile with a hardness in instances of the order of several times that of work-hardened manganese steel. The hardening is not a matter of mere surface hardening but is present to substantial depths and, in many cases, throughout the cross-sectional dimensions of the material. My method is useful even with alloy steels having a high carbon content such as above 0.5% despite their sensitivity to heat and the tendency to anneal at high temperatures. With hollow metal objects, selectivity of hardening effect is afforded by the adaptability of my invention to

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hardening such pieces by disposing the explosive externally and the absorbent coating internally or just the reverse, depending upon which surface is to be subjected to the maximum compressive stress and which the maximum tensile stress. Irregularity of shape or inaccessibility of surface presents no problem in the use of my invention. Thus, it is well adapted in commercial practice of hardening steel plates for armament, plow blades, tools, drills, shovels, machinery with sharp corners, coal and oil transporting beds, dies, mining drill rods and bits, loading machine bucket teeth, crane hooks, Caterpillar tractors, to mention only a few adaptations.

My invention is not to be limited to any of the details above described, except as the appended claims require.

I claim:

1. The method of hardening, by the use of explosive, a material such as metal having a plurality of surfaces and having a predetermined density and velocity of sound propagation, which comprises applying in proximity to one of its said surfaces an explosive having a velocity of detonation substantially exceeding the said velocity of sound propagation in the material, applying to another surface of the material a substance having a density lying within the range of from about 40% to 70% that of the material to be hardened and having a velocity of sound propagation lying within the range of from about 15% to about 40% that of the material to be hardened, detonating the said explosive, and hardening the material by the compressive and tensile stresses within the material thereby generated.

2. The method of hardening, by the use of explosive, a material such as metal having a plurality of surfaces and having a predetermined velocity of sound propagation and specific acoustic resistance, which comprises applying in proximity to one of its said surfaces an explosive having a velocity of detonation substantially exceeding the said velocity of sound propagation in the material, applying to another surface of the material a substance having a specific acoustic resistance lying within the range of from about 5% to about 30% that of the material to be hardened, detonating the said explosive and hardening the material by the compressive and tensile stresses within the material thereby generated.

3. The method of claim 2 in which the said substance is applied to said other surface in a layer of a thickness not less than about the length of the compressive stress wave reaching said surface and within the range of from about ¼ inch to about 1 inch.

4. The method of claim 2 in which the substance is selected from the group consisting of hydrocerussite, barium sulfide, manganese dioxide, ferric oxide, and aluminum oxide.

5. The method of explosively hardening an object, such as of metal, having a plurality of surfaces, which includes the steps of applying to one surface an explosive charge of predetermined high magnitude, less than destructive, adequate to generate stresses of a strength to travel through the metal as compressive stresses to reach another surface and to be reflected internally from said other surface as tensile stresses of a magnitude exceeding the critical tensile stress of the material, and reducing the reflected tensile stresses to a magnitude below the critical tensile stress by applying to said other surface a material which conducts away excessive stresses, whereby from a single detonation the body is hardened by compressive stresses of high magnitude at and below one surface and by tensile stresses less than the critical tensile stress at and below another surface.

6. The method of explosively hardening an object of a material such as metal, having a plurality of surfaces and a predetermined specific acoustic resistance, which includes the steps of applying to one surface an explosive charge of predetermined high magnitude, less than destructive, adequate to generate stresses of a strength to travel through the metal as compressive stresses to reach

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another surface and to be reflected internally from said other surface as tensile stresses of a magnitude exceeding the critical tensile stress of the material, and reducing the reflected tensile stresses to a magnitude below the critical tensile stress by applying to said other surface a material having a specific acoustic resistance in the range of from about 10% to about 20% that of the material to be hardened, which conducts away excessive stresses, whereby from a single detonation the body is hardened by compressive stresses of high magnitude at and below one surface and by tensile stresses less than the critical tensile stress at and below another surface.

7. The method of explosively hardening an object of a material such as metal, having a plurality of surfaces and having a predetermined density and velocity of sound propagation, which includes the steps of applying to one surface an explosive charge of predetermined high magnitude, less than destructive, adequate to generate stresses of a strength to travel through the metal as compressive

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stresses to reach another surface and to be reflected internally from said other surface as tensile stresses of a magnitude exceeding the critical tensile stress of the material, and reducing the reflected tensile stresses to a magnitude below the critical tensile stress by applying to said other surface a material having a density lying within the range of from about 50% to about 60% that of the material to be hardened and having a velocity of sound propagation lying within the range of from about 20% to about 30% that of the material to be hardened, which conducts away excessive stresses, whereby from a single detonation the body is hardened by compressive stresses of high magnitude at and below one surface and by tensile stresses less than the critical tensile stress at and below another surface.

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