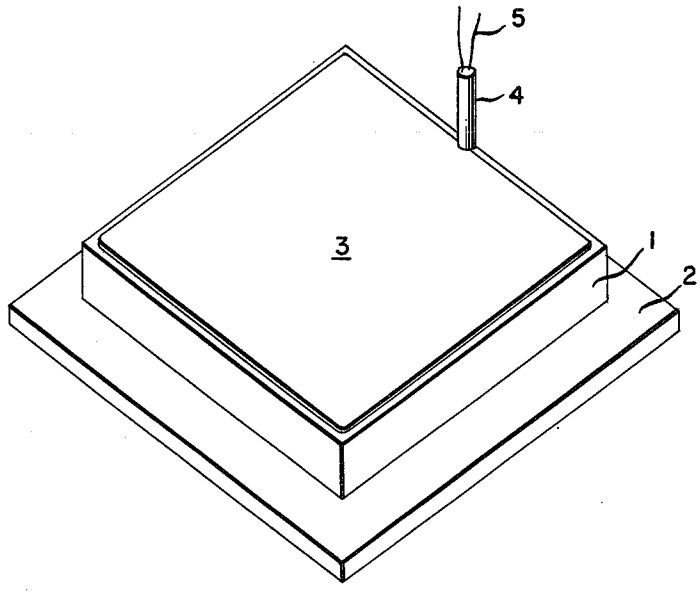
March 19, 1963 C. O. DAVIS ETAL 3,081,498

EXPLOSIVE METHOD OF POWDER COMPACTION

Filed Nov. 13, 1958 2 Sheets-Sheet 1

FIG. 1



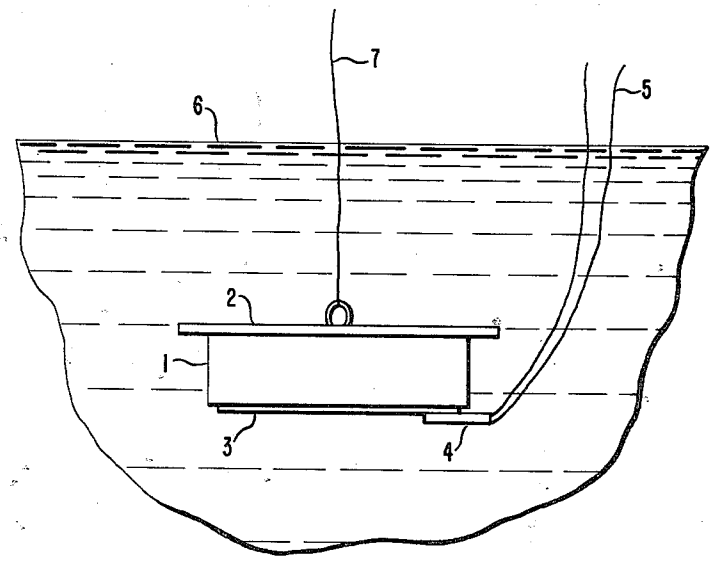
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EXPLOSIVE METHOD OF POWDER COMPACTION

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FIG. 2



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EXPLOSIVE METHOD OF POWDER COMPACTION

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The present invention relates to a process for compacting powders into the form of a slab. More specifically, the present invention pertains to a novel method for preparing compacts in the form of a slab wherein the area of the compact is not restricted by mechanical limitations.

The fabrication of powders into formed articles, known as the art of powder metallurgy, has been the subject of periodic investigations dating back to biblical times when gold and silver powder were pounded into flakes to illustrate and/or illuminate manuscripts. The introduction and subsequent improvements in mechanical devices permitted the compression of powders into objects larger and more coherent than flakes; the resulting consolidated mass being termed a compact. The theoretical value of this art is unlimited. It provides a potential method for preparing compacts having controlled dimensions and densities as well as compacts possessing unique physical properties, such as tensile strength, ductility, etc. Additionally, powder metallurgy permits the combining of powders possessing dissimilar characteristics and/or natures to obtain compacts having the desired properties of the individual components; for example, powdered graphite and copper can be consolidated to produce a product having the high conductivity of copper and the lightness of graphite. Industrially, one of the most important applications of powder metallurgy, and the impetus of the recent, progressive interest in the field, is the fabrication of refractory metals, such as titanium and niobium, which possess valuable physical properties but which can not be prepared conveniently by the conventional techniques of melting and casting due to their extremely high melting points.

Despite the progress in the field provided by mechanical advances, a plurality of difficulties still beset the powder metallurgist. The conventional procedure for producing compacts comprises introducing the loose powder into a suitably designed die and hydraulically or manually pressing, generally employing pressures of from 4,000 to 200,000 pounds per square inch, the specific pressure selected depending on the nature of the powder and the desired properties and size of the compact. Obviously, the expense of the die and the press are governed by the amount of pressure required to compact the powder to the desired extent. Additionally, the configuration of both the die and the piston face must equal the configuration of the compact. So for a given powder compressed to a specific density, the size of the compact is currently limited by economic and mechanical considerations. Furthermore, the most superior compacts with respect to strength are those having substantially theoretical density, i.e., the maximum density the solid product can possess. Since the density of the compact is directly proportional to the pressure applied per unit area which, in turn, is reflected in the power and size of the necessary press, economic considerations also limit the density of the compact presently fabricated. A further restriction along this same line is inflicted by the compression ratio. Normally, the compact will occupy no more than ½, and often as low as 1/16, of the original volume, and thus the stroke of the press and the size of the die must be able to compensate for this reduction in volume. Long strokes of the press, particularly at the extremely high pressures often required, are not feasible.

Further factors to be considered in the compaction of powders and which limit the size of the compact produced are imposed by the powder itself. The powder resists compaction, the magnitude of the resistance being dependent on the physical characteristics of the powder, i.e., density and the depth of the powder. Additionally, when under pressure, the powder does not behave as a "perfect" liquid due to interparticle friction and friction on the die walls.

One method devised to reduce the aforediscussed limitations on compact size and density involves heating the powder in the die prior to compressing. Although this "hot-pressing" reduces the pressure required to obtain a desired degree of compaction, it presents other disadvantages which greatly attenuate the desirability of the process, such as an increase in both the initial equipment cost and the production time due to the added heating and cooling cycle.

After the compacting operation has been effected as outlined previously and subject to the aforesaid limitations, the product generally requires further processing due to its low "green strength," i.e., the amount of coherence of the compressed powder. This supplementary processing normally consists of or includes sintering which involves heating the compact to a temperature just below the melting point of the major constituent of the powder. Although the exact nature of the operation is not fully understood, at this temperature, recrystallization and particle growth acros the particle boundaries occur, yielding a solidified, strengthened compact in which the particles are no longer individually distinct. Depending on the exact properties desired, further repressing and resintering also may be necessary.

The molding of powders into consolidated masses, as hereinfore described, is applicable to many materials in addition to pure metals. For instance, in view of the growing need for articles composed of metal oxides, borides, silicides, carbides, and nitrides, techniques have been developed to manufacture compacts so composed. Non-metallic compacts, of carbon, silicon, organic compositions, polymeric compositions, or mixtures thereof have been prepared analogously. Metals have been compacted with many other materials such as binders, lubricants, etc., to provide unique compositions; an example being the so-called self-lubricating bearing. The complications and limitations associated with the fabrication of the aforenamed powders by mechanical means are generally as severe and unsolvable as those discussed in detail for metal powders.

As can be seen, the realization of the potential of powder metallurgy presently is precluded by limitations and restrictions inherent in the mechanical procedures of fabrication. The current method of compaction requires expensive machinery and is capable of manufacturing compacts of only limited size and density, the usual density being approximately 50–70% of the theoretical density. Furthermore, the compacts thus produced usually require supplementary processing in order to be usable, thereby increasing the time and expense of the operation. In addition, at present, it is virtually impossible to eliminate pores in the compact which both weaken the product and partially account for its low density relative to the theoretical density. If the foregoing difficulties can be overcome successfully without the introduction of additional complications, powder metallurgy offers unlimited possibilities in the fabrication of articles possessing desirable and unique characteristics.

Accordingly, an object of the present invention is to provide a novel method for compacting powder into the form of a slab wherein the disadvantages inherent to conventional methods are overcome. A further object is to compact powder into the form of a slab by utilizing

the compressive force of a high-velocity detonating explosive to provide the compacting pressure. Another object of the present invention is to provide slab-shaped compacts of essentially theoretical density. Additional objects will become apparent as the invention is described in greater detail.

We have found that the foregoing objects are attained when we introduce the powder to be compacted into a container, the loaded container having at least two substantially parallel surfaces, hereafter distinguished by the terms "top" and "bottom," position a layer of a high-velocity detonating explosive in a plane conormal to the top of the container, the area configuration of said explosive layer conforming approximately to the area configuration of the top of the container, and thereafter initiate said explosive. In order to minimize damage of the compact due to rarefaction, we prefer to incorporate a means to attenuate the magnitude of the tension waves. When the powder is in a rectangular container, we prefer to initiate the explosive layer at a single point on one of the edges of said layer or at a plurality of points along a single edge in order to reduce the likelihood of cracking at the corners and edges of the compact.

In order to describe the invention more fully, reference now is made to the accompanying drawings. The figures are illustrative only and are not to be construed as limiting the invention in any manner. Referring specifically to FIGURE 1, **1** represents a rigid, parallel-epipedal container, e.g., of aluminum, holding the powder to be compacted. Adjacent to the bottom of the container is a metal plate **2**, e.g., steel. A layer of a high-velocity detonating explosive **3** having a length and width a little less than the corresponding dimensions of the container **1** is taped to the top of the container. An electric initiator **4** with lead wires **5** is fastened to the midpoint of one of the edges of the explosive layer **3**.

In the sequence of operation of the present invention, the actuation of the initiator **4** by the passage of electric current through the lead wires **5** initiates the explosive layer **3**. The resulting detonation proceeds across the explosive layer **3**, the blasting force compacting the powder in the container **1**. The metal support plate **2** adjacent the container attenuates the magnitude of tension waves reflected back into the powder, thus minimizing the possibility of cracking and spalling of the compact.

FIGURE 2 illustrates a specific method of carrying out this invention wherein the assembly shown in FIGURE 1 is inverted and suspended in water **6** by means of a cable or chain **7** attached to an eyehook which is attached to metal plate **2**. In FIGURE 2, elements **1** to **5** have the same significance as elements **1** to **5** in FIGURE 1 and operate in the same manner as described above with reference to FIGURE 1.

In order to describe the invention further, reference now is made to the following examples, which are illustrative only and are not to be construed as limiting the invention in any manner. In the examples, the explosive layer consisted of a sheet explosive prepared by mixing 85 parts of PETN, 7.5 parts of butyl rubber, and 7.5 parts of a thermoplastic terpene resin (mixture of β-pinene polymers having the formula $(C_{10}H_{16})_n$ and commercially available as "Piccolyte" S–10, manufactured by the Pennsylvania Industrial Chemical Corporation). The final blend was rolled into sheets, the thickness of which determined the weight of explosive per unit area. The composition has a velocity of detonation of approximately 7000 meters per second, and the sheets are strong, flexible, and non-resilient.

Example 1

An open aluminum container 8 inches square, 3 inches deep, and having a wall thickness of ⅛ inch, the sides and bottom of which were welded together, was vibrator packed with titanium sponge (commercial grade) to a density of 1.4 grams per cubic centimeter. An aluminum top was taped to the loaded container, and the external surface of the top was covered by the described explosive which had an explosive loading of 7 grams per square inch. A commercial detonator was fastened to the midpoint of one of the edges of the explosive layer. The bottom of the container was placed on a steel support plate, 10 inches square by 1 inch thick, and the entire assembly was immersed in water. The initiator was actuated by the passage of electric current through the lead wires and initiated the explosive layer. The container was recovered, and the compact removed therefrom.

The compact thus produced was very strong, had the appearance of a solid metal plate with a thickness of 1 inch, and had a density greater than 95% of the theoretical density.

Example 2

Atomized aluminum powder was vibrator packed to a density of 1.55 grams per cubic centimeter into an aluminum container identical to that described in Example 1. The described explosive sheet having 4 grams of explosive per square inch was glued onto the aluminum top. A steel plate 6 inches square by 3 inches thick was centered over the explosive. A line wave generator was attached to one side of the explosive layer, an engineers' blasting cap being fastened to the apex thereof. This line wave generator was a continuous sheet-like triangular matrix of a high explosive containing a plurality of apertures of dimensions sufficient to prevent the propagation of the detonation wave across the apertures and arranged so as to delineate a series of paths from the initiation point to each of a plurality of finish points, the shortest distance thereof from the initiation point to each finsh point being equal. Thus, when a vertex of the triangle is used as the initiation point, the detonation front arrives simultaneously at a plurality of points on the opposite side from the point of initiation. The assembly was placed on a steel support plate as described in Example 1 and immersed in water until the water level coincided with the interface of the container and top thereof. The initiator was actuated at a vertex.

The compact produced was well consolidated, had a density greater than 95% of the theoretical density, and was free of cracks and spalls.

Example 3

The procedure outlined in Example 1 was followed except that the described container was filled to a 1.5-inch depth with electrolytic iron powder and the remaining 1.5 inch was filled with aluminum powder. The iron powder served as a support for the aluminum powder.

The aluminum compact produced was ⅞ inch thick, free of visible cracks, and well consolidated. A transverse slab cut from the compact was used to determine "green" tensile strength and gave a measurement of 10,400 pounds per square inch.

Example 4

An aluminum container having the same dimensions as that described in Example 1 except for the wall thickness thereof which was 1/16 inch was vibrator packed with electrolytic iron to a density of 3.7 grams per cubic centimeter. The described explosive, the loading being 6 grams per square inch, was glued onto the top of the container. The container was placed on a steel support plate, the assembly immersed in water, and the explosive initiated as described in Example 1. The container was recovered and inverted, and the procedure was repeated on the opposite surface of the container, a second explosive loading identical to the first being used. The assembly was reimmersed in water, and the initiator was actuated.

The compact produced by this two-step procedure was 1.5 inches thick, well consolidated, and free of spalls.

Example 5

A dendritic titanium compact was prepared in the following manner. Aluminum powder was vibrator packed into the bottom ⅛ inch of an aluminum container 10 inches square and 2 inches thick. A polyethylene film was placed over the loaded aluminum powder, and the remainder of the container was loaded with dendritic titanium. The top of the container, the external surface of which was covered by the described explosive having an explosive loading of 4 grams per square inch, was taped to the container. The means for initiation was identical to that described in Example 2. The base of the container rested on a steel plate 12 inches square and 1 inch thick, and the entire assembly was submerged in water. The initiator was actuated.

The resulting titanium compact was ⅜-inch thick and well compacted.

Example 6

Dendritic titanium was vibrator-packed to a bulk density of 1.54 grams per cubic centimeter into an aluminum container 10 inches square, 2 inches deep, and having a wall thickness of ⅛ inch. The described explosive sheet having an explosive loading of 6 grams per square inch was glued to the external surface of the container top. A line wave generator identical to that described in Example 2 was fastened to one side of the explosive sheet. The loaded container was placed on a 6-inch-thick steel plate, and the sides of the container were surrounded by ½-inch-thick lead. The assembly was immersed in water, and the explosive was initiated.

The resulting compact, 0.72 inch thick, was well consolidated and essentially free of spalls.

As can be seen in the foregoing examples, flat powder compacts can be produced easily and quickly by the method of the present invention. The density of all the resulting compacts was 95% or over, and a tensile strength specimen taken from the aluminum compact prepared in Example 3 gave a measurement of 10,400 pounds per square inch. The proceeding data conclusively show the superiority in both density and strength of the method of the present invention compared to prior methods of compacting powders.

The present method of compacting powders has been exemplified with aluminum, iron, and titanium powders. However, this method is equally applicable to any compressible powder, such as red-lead, Carborundum, copper, ferrosilicon, iron oxides, etc. The invention will find extensive use also in compacting refractory metals, such as niobium and titanium, and for compacting powders containing hard and/or abrasive particles. In essence, then, the present method is suitable for any powder that can be mechanically computed, and indeed to some that previously could not be compacted. Because the explosive layer can be made as large as desired, no limitation exists with respect to the area of compact so produced. The depth of the compact, being proportional to the loading of the explosive layer, can be controlled easily, and very thick slabs can be made. If necessary, repetitive shots can be made to avoid the requirement of very thick layers of explosive for compacts of unusual depth. As shown previously, this flexibility in the size of the compact prepared is not evident in the mechanical compaction of powders, and represents a significant advance in the art of powder metallurgy. Additionally, it has been shown that substantially theoretical densities are attained by the novel compaction method of the present invention. Inasmuch as the strength and working characteristics of a compact are directly proportional to its density, the obtaining of such high densities in a single operation is of tremendous value. For many fabrications, the compacts thus formed can be used directly. If supplementary processing is desired, the higher density and strength and greater uniformity of the compact compared to compacts produced by conventional means increases the quantity of material in a compact of a specified size as well as causing a more uniform and regular melting zone, the latter feature permitting the elimination of the remelting operation previously required in order to attain a uniform billet.

The very high densities that can be obtained by explosive compaction are ascribable to the behavior of particulate matter exposed to a shock wave. When an explosively produced shock front moves through a powder, the shock is characterized by a very high particle velocity. This high velocity results in large magnifications of pressure when two particles impact together. Deformation and yielding of the particles then result in the high density compacts that are characteristically obtained. As the distance between the explosive and the powder increases, the explosive loading must increase correspondingly in order to counterbalance the attenuation of the shock as the wave passes through the intervening medium. For ease of application and handling as well as the ability to produce satisfactory compacts thereby, we attach the explosive on the external surface of the container top, thereby separating the explosive and the powder to be compacted only by the thickness of said top. However, if desired, the explosive may be placed at a distance apart, with the intervening medium being selected from any of the known shock transmitting agents. In the latter case, a sufficient loading of the explosive is employed to compensate for the loss of pressure due to the added distance and the shock absorption ability of the medium.

The explosive selected to compact the powder in accordance with the method of the present invention must detonate at a relatively high velocity in order to provide the magnitude of pressure required. By the term "high-velocity detonating explosive," we means a composition having, when unconfined, a velocity of detonation of more than 1200 meters per second. The particular explosive selected in compliance with the above definition is not critical to the present invention and will depend primarily on the degree of compaction desired and the size of the compact to be prepared. As is readily apparent, the quantity of explosive used must be sufficient to guarantee propagation of the detonation throughout the explosive layer. In the case of a thin compact, the quantity of explosive per unit area required is so small that the less sensitive compositions, such as HMX, RDX, TNT, and the like, would not propagate the detonation. On the other hand, the more sensitive explosives, such as PETN, and nitroglycerin-based compositions, will propagate detonation in thin layers as well as thick layers. Consequently, when compacts having a large depth are desired, a much wider range of explosive compositions can be used satisfactorily.

In the examples, a sheet explosive containing a PETN-binder composition was employed to provide the compacting energy. This form of explosive is advantageous because of the ease of handling and of controlling the loading density. However, the invention is not to be construed as limited to sheet explosives. Blasting gelatin or powders held in suitable containers are applicable and can be employed.

The initiating means is not critical to the present invention. In order to eliminate cracking and spalling due to edge and corner effects of parallelepipedal compacts, we initiate one side of the layer at a single point or a plurality of points along one side. Simultaneous initiation of the entire sheet is also contemplated. As is obvious, when round compacts are desired, initiation on any point on the explosive layer is feasible.

In order to reduce noise and air blast from the detonation of the high explosive, we prefer to effect the operation under water. Another beneficial feature of submerging the assembly in water prior to initiation is that tension waves, which are caused by the difference in sonic impedances in the two media are reduced, correspondingly decreasing the possibility of compact shattering. The

water also serves to provide additional confinement to the assembly which permits the use of a smaller quantity of explosive to obtain a compact of a specified size and density. However, the water is not required to transmit the pressure of the explosive detonation, and, so, no confinement of the water is necessary. Obviously, when the assembly is submerged, the explosive composition must be water resistant.

The container holding the powder to be compacted may be of any composition, provided that it is water resistant in those cases wherein submergence prior to initiation is desired. Containers composed of polyethylene, cardboard, metals, and the like are contemplated. If desired, the container may be composed of the same material as the compact, thereby eliminating the necessity of removing the compact. Likewise, in those applications where removal of the compact is unnecessary or undesirable, the container may be so composed as to provide additional strength to the compact. As is obvious, the shape of the container depends on the shape of the desired compact although it will be recognized by those skilled in the art that extreme geometrical configurations may introduce complications.

The presence of a substantial thickness of a material having a density of at least 1 gram per cubic centimeter adjacent the bottom of the powder is also preferred. Such material serves to attenuate the effect on the powder compact of the tension waves reflected from the interface of the container and the adjacent medium. Thus, spalling and cracking of the compact due to rarefaction of the tension waves is precluded or, at least, minimized. Due to the ease of handling, we prefer to utilize a steel or other metal plate which has an effective cross-sectional area, i.e., the area in contact with the container, equal to or greater than the area of the bottom of the loaded container. Other materials, such as earth, water, etc., also are suitable and may serve as the support material. If the presence of an additional material is not desirable, the same advantages are obtained by increasing the thickness of the bottom of the container. Also, as exemplified, very good compacts are obtained by reinforcing (either by building up the thickness thereof or by positioning a support material adjacent thereto) the sides of the container as well as the bottom of the container. Obviously, the two support material may be the same or different. As shown by the examples, the support materials may be inside, e.g., a support powder, or outside of the container.

In those cases where the presence of a gas may be deleterious to the powder being compacted, the assembly may be evacuated prior to the detonation of the explosive layer. If only air is objectionable, an inert gas may be substituted for the air. In a similar way, any gas known to impart desirable characteristics to the powder may be incorporated in the assembly.

As stated previously, flat compacts of various configurations, e.g., round, rectangular, etc., may be produced in accordance with the present invention. Additionally, the present invention is applicable to producing compacts having undulated, tilted, or irregular surfaces by employing a suitably shaped container by introducing bars or the like into the powder and removing them after compaction of the powder. Also, if desired, mandrels may be incorporated in the powder to fabricate compacts containing controlled voids. In such a case, wear on the mandrels and cracking of the die due to the geometry of the configuration is avoided by covering the mandrel with adequate powder to insure that the compaction will not reduce the powder layer below the position of the mandrel. Similarly, wires or other reinforcing elements may be placed in the powder prior to compaction.

Also, the powder may be heated prior to being compacted. Induction heating can be used to heat powders in the container, and an explosive having thermal stability can be used. Furthermore, a magnetic field can be impressed on the powder to orient the magnetic material in the powder prior to compaction.

The invention has been described in detail in the foregoing. Many modifications and variations not specifically discussed that lie within the scope of the invention will occur to those skilled in the art. Accordingly, we intend to be limited only by the following claims.

We claim:

1. A method for compacting powder into slab form which comprises loading said powder into a container having at least one pair of essentially parallel sides, interposing said parallel sides of said container between ann conormal to a layer of detonating explosive and an attenuating material, said layer of explosive having an area configuration substantially equivalent to that of said side of said container adjacent thereto and said attenuating material having a density of greater than 1, and thereafter initiating said explosive layer.

2. A method as claimed in claim 1 wherein said container is sealed and the assembly of container attenuating material and explosive immersed in water prior to initiation of said explosive layer.

3. A method as claimed in claim 1 wherein the explosive layer comprises PETN.

4. A method as claimed in claim 1 wherein said layer of explosive is in the form of a sheet having a substantially uniform loading of explosive per unit of area.

5. A method for compacting powder into slab form which comprises loading said powder into a container having at least one pair of essentially parallel sides, positioning a layer of a detonating explosive on the outside of said container conormal to one of said parallel sides, said layer of explosive having an area configuration substantially equivalent to the area configuration of said side, the thickness of said powder between said parallel sides of said container exceeding that required to form a slab of the desired thickness whereby the excess powder serves to prevent damage to the compacted powder by attenuating the rarefraction following the detonation of said explosive layer, and thereafter initiating said explosive layer.

6. A method for compacting powder into slab form which comprises loading said powder into a container having at least one pair of essentially parallel sides, positioning a layer of a detonating explosive on the outside of said container conormal to one of said parallel sides, said layer of explosive having an area configuration substantially equivalent to the area configuration of said side, the parallel side of said container opposite the side adjacent said explosive layer being of sufficient thickness to prevent damage to the powder compact from rarefraction following the detonation of said explosive layer, and thereafter initiating said explosive layer.

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