United States Patent

[11] 3,599,460

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[21] Appl. No. 731,098
[22] Filed May 22, 1968
[45] Patented Aug. 17, 1971

[54] METAL-TREATING PROCESS AND APPARATUS
8 Claims, 4 Drawing Figs.

[52] U.S. Cl. 72/53
[51] Int. Cl. C21d 7/06
[50] Field of Search 72/53, 40; 51/319, 321

[56] **References Cited**

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2,249,678	7/1941	Wallace	72/53
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OTHER REFERENCES

" The Friction and Lubrication of Solids" by F. P. Bowden and D. Tabor (Dept. of Physical Chemistry, Cambridge) Oxford At the Clarendon Press (1954). (A copy is attached to the amendment of June 4, 1970, in the file)

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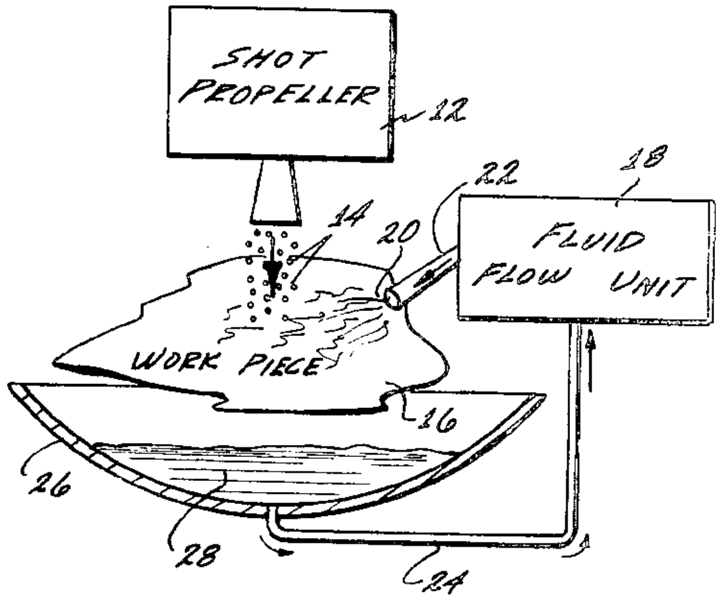
ABSTRACT: A system is disclosed for processing metallic members, to accomplish residual compressive stresses in surfaces thereof. It has been discovered that the provision of a defined fluid film over a metal member, while the member undergoes surface cold working (as by peening) accomplishes more effective peening without substantial attendant surface damage. This unexpected improvement stems from the use of a fluid having a pressure coefficient of viscosity which is above a critical level and as somewhat related to the modulus of elasticity of the metal undergoing surface treatment. Specifically, for example, in peening steel, a fluid is required having a pressure coefficient of viscosity which is substantially at least 7×10^{15} p.s.i. ^{11}. As a specific example of such a fluid, mineral oil may be employed along with oxidation inhibitors and other additives.



METAL-TREATING PROCESS AND APPARATUS

BACKGROUND AND SUMMARY OF THE INVENTION

Several different types of manufacturing processes involve cold working metal surfaces. It is such processes to which the present invention is applicable. Specifically, for example, one form of cold-working manufacturing process involves shot peening, wherein shot, usually in the form of small metal cylinders or spheres is propelled to impact upon the surface of a metallic workpiece that is undergoing treatment. The peening process has two pronounced effects. The desired effect is the development of residual compressive stresses in the surface regions of the workpiece which tend to prevent the growth and development of fatigue cracks to thereby substantially increase the life of the workpiece in fatigue applications. Specifically, for example, springs, axles, crankshafts, aircraft wing parts, and so on, are traditionally shot peened to improve their resistance to fatigue failure.

The second effect of shot peening is surface damage (normally in the form of microscopic cracks) and fatigue damage which may eventually result in susceptible failure locations. This damage effect is, of course, undesirable; however, it is somewhat obscured by the desired effect. In some applications, as ball bearings, it has been proposed to remove the cold-worked surface after shot peening to eliminate the external damaged surface. In general, such a technique has been found to be somewhat effective, although rather expensive and time consuming. Recapitulating, substantial advantages result from peening in many applications; however, a need exists for a system of peening which avoids surface damage. Furthermore, in view of the wide extent to which peening and related cold-working process are practiced, a need continues for such a process wherein cold working is more effectively accomplished by a forming member, e.g. shot peen.

Although peening, and similar cold-working metal processes are desirable in many applications, certain metals and alloys are extremely difficult to peen. For example, it is desirable to peen members that comprise somewhat exotic metals as titanium yet, surface contamination of such members must often be avoided. Also, it is desirable to peen members that are formed of certain alloys which have a very high yield strength, however, such strength makes peening quite difficult with conventional methods and apparatus. Prior techniques to accomplish peening have involved increasing the force applied to the shot and the use of special stainless-steel shot. Such techniques are expensive and frequently troublesome. Therefore, a need exists for a cold-working process wherein contamination is substantially avoided and which is capable of more effectively working a workpiece.

In general, the present invention resides in the discovery that cold working processes for metal surfaces can be substantially improved by providing a fluid film over such surface prior to cold working. Specifically, for example, by providing a film of fluid having a pressure coefficient of viscosity of at least 7×10^{15} p.s.i. $^{-1}$, a substantial improvement results. The improvements include these advantages: the cold-working process is more effective, surface damage of the workpiece is avoided, and surface contamination of the workpiece is minimized; all of which results in considerable economy and product improvement.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which constitute a part of this specification, exemplary embodiments are set forth, exhibiting the various objectives of the present invention, specifically:

FIG. 1 is a diagrammatic representation of a system in accordance with the present invention;

FIG. 2 is a diagrammatic representation of another system in accordance with the present invention;

FIG. 3 is a sectional view illustrating the operation of the system of the present invention; and

FIG. 4 is an enlarged fragmentary view of FIG. 3.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

As required, detailed descriptions of illustrative embodiments are set forth herein. However, it is to be understood that the specific structural and functional details disclosed herein are provided merely as a basis for the claims actually defining the scope of the invention.

Referring initially to FIG. 1, there is shown a shot propeller 12 which may take any of a variety of different forms capable of functioning to propel shot 14 forcefully against a workpiece 16. The shot propeller 12 may take any of a variety of different forms, as well known in the prior art specifically including centrifugal force shot propelling structures, airblast shot propelling units and so on. Similarly, the shot 14 may take various forms as well known in the prior art which in accordance herewith will normally be spheres or cylinders of ferrous metal.

The workpiece 16 is the object of the process under illustrative description. As indicated above common workpieces for treatment in accordance with the hereof process include such machine components as springs, axles, crankshafts, aircraft wing spars, aircraft propellers, and so on. Of course, such workpieces may comprise various metals and alloys.

As shown in FIG. 1, a fluid-flow unit 18 dispenses liquid 20 to accomplish and maintain a thin film on the workpiece 16. In accordance with the present invention, unexpectedly, the provision of a film comprising a specific class of fluids on the workpiece 16, so as to receive the shot 14 at the point where it impacts the workpiece 16, accomplishes greatly improved results in the process of shot peening the workpiece.

The fluid-flow unit 18 may comprise simply a pump (not shown), as well known in the prior art, for dispensing liquid to a discharge trough 22. The fluid-flow unit 18 is coupled through a return duct 24 to a catch basin 26 which receives liquid as it drains from the workpiece 16 to accumulate a reservoir 28. Thus, a film of the liquid is provided and maintained on the workpiece 16 coincident with the impacting shot 14.

The shot 14 is propelled from the shot propeller 12 with sufficient energy to actually distort the workpiece 16. That is, an individual shot 14*a* (FIG. 3) produces an indentation 30 in the surface 31 of the workpiece 16 on impact. However, it is to be noted, that the film 32 continues to separate the shot 14*a* from the workpiece 16.

AS a result of the peening process, the surface 31 of the workpiece 16 is distorted to accomplish residual compressive stresses which act to prevent the growth and development of fatigue cracks thereby increasing the life of the workpiece 16 in various applications, particularly those in which the workpiece is subjected to fatigue failure. In accordance with the present discovery, the provision of the liquid film 32 actually increases the effectiveness of the shot 14 in deforming the surface 31 of the workpiece 16. To accomplish such increased deformation, which is akin to rendering the shot peening process more effective, the liquid constituting the film 32 must be of a particular characteristics. In general, the film 32 must comprise a fluid having a pressure coefficient of the viscosity which is at least 7×10^{15} p.s.i. $^{-1}$. This coefficient is frequently identified by the letter α_p in the literature and is defined as

$$e^{\alpha p} = \eta_p/\eta_0$$

where e is the logarithmic constant, e.g. 2.718 .... (base 10), η_p is the fluid viscosity at pressure p and η_0 is the fluid viscosity at atmospheric pressure. The coefficient is considered in *The Principles of Lubrication* by A. Cameron (John Wiley and Sons, Inc.—New York) beginning at page 30. The coefficient α_p can be defined as: $\alpha p = \log_e \eta_p - \log_e \eta_0$ by solving for αp as set forth below.

The following transition formulas will be used in the solution, all of which appear in the CRC Handbook of Chemistry and Physics, 48th Edition (1967–68), at pages A–2 and A–9.

$$\log (a/b) = \log a - \log b$$

$$\log a^n = n \times \log a$$

$$\log_a x = \log_b x / \log_b a$$

Note that b is any base e.g. b can equal 10 which is convenient. The number e is a constant i.e. e=2.718 .... for base 10. There are tables readily available for the $\log_e x$ at various values of x.

Beginning with

$$\eta_p = \eta_o e^{\alpha p}$$

from algebra,

$$e^{\alpha} p = \eta_p / \eta_o$$

taking the logarithms of both sides (using base e)

$$\log_e e^{\alpha p} = \log_e (\eta_p/\eta_o)$$

using the second formula above for a transition,

$$\alpha p (\log_e e) = \log_e (\eta_p/\eta_o)$$

using the third formula above.

$$\alpha p (\log_b e / \log_b e) = \log_e (\eta_p/\eta_o)$$

from algebra

$$\alpha p \times 1 = \alpha p = \log_e (\eta_p/\eta_o)$$

then to simplify, using the first formula above

$$\alpha p = \log_e \eta_p - \log_e \eta_o$$

Accordingly, as stated herein, the fluid for use in the process hereof may be specified by having a characteristic coefficient of pressure viscosity which exceeds a predetermined value. Various techniques exist for determining a value for each fluid; however, as stated mathematically above, the value can be determined on the basis of two fluid viscosity measurements, η_o and η_p. This is, using these measurements of viscosity,

$$\alpha p = \log_e \eta_p - \log_e \eta_o$$

= coefficient of pressure viscosity

which value in the more effective practice of the present invention is at least 7×10^{15}(0.00007).

As indicated the film 32 under the shot 14*a* (FIG. 3) impacting along the line of an arrow 34, against the workpiece 16 significantly improves the forceful distortion of the surface 31. In general, this increased effectiveness results from, or is related to, the variation in viscosity as related to pressure for the liquid constituting the film 32. More specifically, the fluid comprising the film as provided herein must have a significant pressure coefficient of viscosity or the process hereof is not effective. In that regard, water (pressure coefficient of viscosity 5×10^{16} p.s.i. $^{-1}$) is not effective. Conversely, mineral oil, having a pressure coefficient of viscosity of 2×10^{14} p.s.i. $^{-1}$ has been found particularly effective. In this regard, detailed analysis and experimentation indicates that the fluid comprising the film must have a pressure coefficient of viscosity of at least 7×10^{15} p.s.i. $^{-1}$ for the process hereof to be effective. Various hydrocarbon liquids meet that standard and are generally nonoxidizing. However, various well-known agents to avoid metallic oxidation may also be added.

The selection of the fluid comprising the film may depend to some extent upon the material of the workpiece in process. That is, in general, as the modulus of elasticity of the material in the workpiece increases, the pressure coefficient of viscosity of the fluid comprising the film 32 may decrease with some compensating effect. In this regard, it has been determined by experimentation and analysis that an effective criterion may be established by multiplying the modulus of elasticity of the material to be shot peened by the pressure coefficient of viscosity of the film fluid to accomplish an arbitrary numerical value. In the practice of the invention, that arbitrary value should not be less than 1,400.

Considering a specific example of processing, assume it is desirable to peen a steel workpiece employing shot which also comprises steel. The modulus of elasticity for steel may be taken as: 30×10^6 p.s.i. which is divided into the dimensionless guide figure of 1,400 to result in a value of: 8.5×10^{15} p.s.i. $^{-1}$. Therefore, the indication is that the pressure coefficient of viscosity of the fluid to be employed in the assume example must be at least 8.5×10^{15} p.s.i. $^{-1}$. Various refined mineral oils possess a characteristic pressure coefficient of viscosity considerably higher than this figure with the result that such oils are effective for use in shot peening steel. In this regard, it is to be noted that mineral oil actually has a pressure coefficient of viscosity that is over twice the requisite minimum.

Although the mathematical analysis hereof has been accomplished and effectively substantiates test results and actual practice, the detailed physical aspects of the phenomena involved are neither entirely apparent nor simply explained. It has been established that while the pressure coefficient of viscosity of the fluid is a key consideration, the static viscosity thereof appears to be quite immaterial. The physical basis of the process is the high hydrodynamic pressures generated when the fluid (to be squeezed out of the nominal contact zone) has a high pressure coefficient of viscosity. As a result, as the shot 14*a* (FIG. 4) forcefully encounters the workpiece 16 (thereby applying compressive forces to the film 32 as indicated by the arrows 36) the increased pressure on the film 32 increases the viscosity of that liquid resulting in a further increase in the fluid pressure, thereby increasing the effectiveness of the impacting shot 14*a*. In any event, the film carries forces as indicated by the arrows 38 to apply the forceful impact of the shot 14*a* to the workpiece 16.

Recognizing that analysis of the detailed forces involved in the practice of the present invention and the philosophy thereof are extremely complex, it is to be emphasize that actual practice and mathematical analysis fully establish the improvements hereof. In addition to the increased effectiveness of the shot peening operation, other substantial, unobvious and unexpected results also occur. Specifically, in addition to increasing the depth of the indentation 30, (FIG. 3), the microcracks and fatigue damage normally developed in prior shot-peening systems are substantially avoided herein. As a result, a structure with residual compressive stresses in the surface region may be accomplished without surface microcracks and without the surface removal as by chemical etching.

Another unobvious feature of the present invention stems from its applicability of the shot peening of structures which in the past were difficult to process. For example, in shot peening titanium members metallic contamination has been a substantial problem due to the transfer of metallic particles from the shot to the titanium structure. However, in utilizing the system of the present invention for shot peening, the film 32 (FIG. 3) affords a shield between the shot 14 and the workpiece 16 thereby avoiding the transfer of metallic particles from the shot to the workpiece. As a result, in accordance herewith, such prior techniques as the utilization of expensive stainless steel shot can be avoided with considerable economy.

As a related consideration, the shot peening system hereof may also be employed to shot peen alloys having exceedingly high yield strengths, e.g. up to 300,000 pounds per square inch, while using conventional shot-peening mechanisms. That is, due to the increased effectiveness hereof, conventional apparatus may be employed to accomplish the shot-peening of materials having very high yield strengths. Somewhat related to this consideration, it is important to understand that the system hereof may be variously adapted to a wide variety of different shot peening apparatus. For example, various forms of the structure of FIG. 1 may be employed as may forms of the structure of FIG. 2; however, both are merely representative.

Considering the structure of FIG. 2 in somewhat greater detail, a rotary tumbler **40** is carried on supports **42** and mechanically coupled, as indicated by a dashed line **44**, to be driven by a motor or rotary unit **46**. Thus, the tumbler **40** is revolved at a tumbling rate, so as to accomplish shot peening of workpieces **50** carried therein by shot **52** which is also carried in the tumbler. Specifically, the tumbler **40** incorporates a number of lifters **48** which raise the workpieces **50** along with the shot **52** to a location at the top of the tumbler **40**, from which these elements fall in a conventional tumbling motion. Of course, as the shot **52** and the workpieces **50** fall together, the resulting forceful engagement causes peening of the workpieces **50**.

The tumbler **40** is, in part closed by an annular screen **54** extending centrally about the periphery of the tumbler. The screen permits liquid container within the tumbler **40** to flow into a basin **56** from which it is supplied to a pump **58** which is in turn connected to a nozzle **60** (inside the tumbler **40**) through an axial duct **62**.

As the workpieces **50** tumble with the shot **52**, they tend to be substantially covered with a film of liquid; however, by affording the external circulating path for the liquid, to accomplish a spray or mist inside the tumbler, the workpieces are assured of being well covered immediately prior to impact.

Recapitulating, the workpieces **50** and the shot **52** are retained by somewhat-radial internal lifters **48**, to be carried to the top of the path of travel in the tumbler **40**, then dropped through a spray **64** of liquid that is dispensed from the nozzle **60** to pass to the bottom of the tumbler **40** with forceful engagement. Of course, the forceful engagement results in peening workpieces **50** while they are covered with liquid. The liquid employed in the system of FIG. 2 may comprise mineral oil or other liquids meeting the requisite standard. That is, the class of liquids for satisfactory operation in the system must have a pressure coefficient of viscosity in excess of 7×10^{15} p.s.i. ¹¹.

The features and advantages of the system of FIG. 2 are substantially coincident with those of FIG. 1. In this regard, the two independent systems are described to illustrate the fact that the system hereof may be widely applied to a large number of specific and different shot-peening mechanisms. Thus, the invention is set forth to afford a basis for the claims as follows.

I claim:

1. In a process for treating a metal workpiece, as by cold working to increase the life of said workpiece in fatigue applications, which process includes the step of impacting said metal workpiece with at least one forming member, as peen shot, the improvement in the process of providing a fluid between said workpiece and said forming member during impact whereby said forming member deforms said workpiece through a film of said fluid located therebetween, said fluid having a pressure coefficient of fluid viscosity such that under impact of said forming members the viscosity of said fluid rises sharply to increase the pressure effective on said workpiece resulting from impact of said forming members thereon through said fluid, to increase the deformation of said workpiece.

2. A process according to claim 1 wherein said fluid comprises mineral oil.

3. A process according to claim 1 wherein said fluid comprises a fluid having a pressure coefficient of viscosity of at least 7×10^{15}.

4. A process according to claim 1 wherein said fluid comprises a fluid having a pressure coefficient of viscosity value and said workpiece has a modulus of elasticity value, the product of which values exceeds 1,400.

5. A process according to claim 1 wherein said fluid comprises a liquid hydrocarbon and said forming member comprises a ferrous metal.

6. A metal processing apparatus for surface treating a workpiece, as by cold working, with peening shot to alter the characteristics thereof, comprising:

- means for propelling said shot to impact on said workpiece, and
- means for providing a fluid film between said workpiece and said peening shot, said fluid film comprising a fluid having a pressure coefficient of fluid viscosity such that under impact of said forming members the viscosity of said fluid rises sharply to increase the pressure effective on said workpiece resulting from impact of said peening shot, to increase the deformation in the surface of said workpiece through said film.

7. A metal-processing apparatus according to claim 15 wherein said means for providing a fluid film comprises a fluid flow means for flowing fluid onto said workpiece.

8. A metal-processing apparatus according to claim 6 wherein said means for providing a fluid film comprises a fluid spray means.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,599,460 Dated August 17, 1971

Inventor(s) Eugene F. Finkin

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column	Line	
Abstract	13	"10^{15} psi^{11}" should be --10^{-5} psi^{-1}--;
1	58	"10^{15} psi^{11}" should be --10^{-5} psi^{-1}--;
2	47	"AS" should be --As--;
2	59	"characteristics" should be --characteristic--;
2	61	"$1\ ^{15}$ psi^{11}" should be --10^{-5} psi^{-1}--;
3	16	"$e^{\alpha}p$" should be --$e^{\alpha p}$--;
3	41	"This is" should be --That is--;
3	49	"10^{15}" should be --10^{-5}--;
3	59	"10^{16} psi^{11}" should be --10^{-6} psi^{-1}--;
3	60	"10^{14} psi^{11}" should be --10^{-4} psi^{-1}--;
3	64	"10^{15} psi^{11}" should be --10^{-5} psi^{-1}--;
4	10	"10^{15} psi$^{1}_{1}$" should be --10^{-5} psi^{-1}--;

FORM PO-1050 (10-69)

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,599,460 Dated August 17, 1971

Inventor(s) Eugene F. Finkin PAGE - 2

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column	Line	
4	13	"10^{15} psi^{11}" should be --10^{-5} psi^{-1}--;
4	40	"emphasize" should be --emphasized--;
5	37	"10^{15}" should be --10^{-5}--;
5	38	"psi^{11}" should be --psi^{-1}--;
6	19	"10^{15}" should be --10^{-5}--;
6	40	"15" should be --6--.

Signed and sealed this 27th day of June 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

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FIG. 1

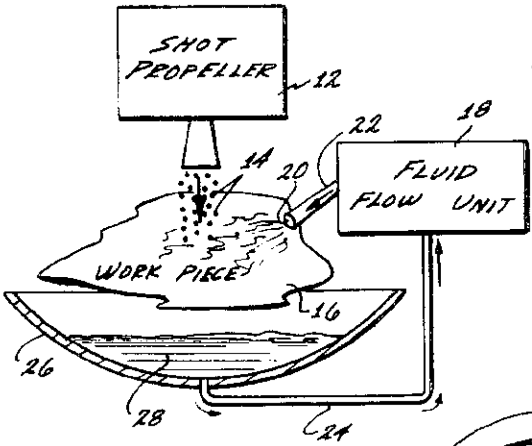


FIG. 2

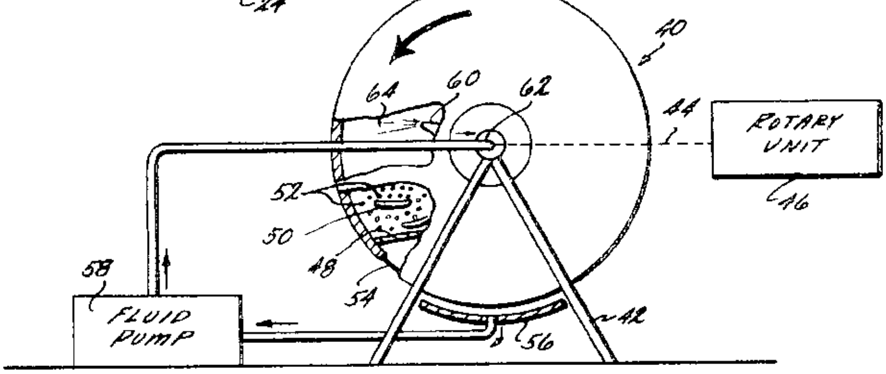
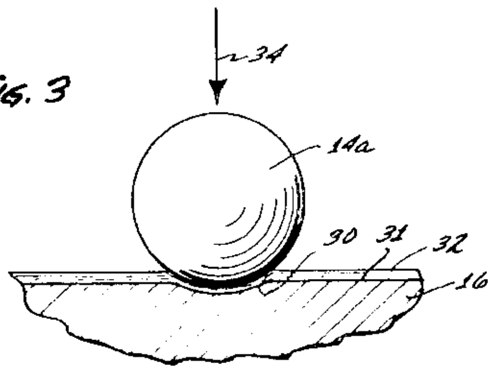


FIG. 3



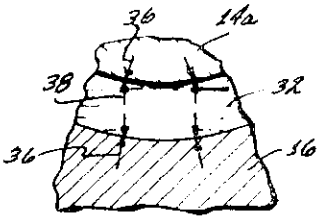


FIG. 4

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