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Examination of High-Pressure Water Jet Usability for High Explosives (HE) Washing Out from Artillery Ammunition

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Abstract: The method of explosives materials washing-out process from old artillery ammunition using high-pressure water jet technology was discussed in the paper. Presented experimental results let to define explosives washing-out mechanism and its potential effectiveness. Finally, exemplary structures of washed-out explosives pointing on methods of its utilization are presented.

Keywords: high-pressure water jet, explosive material, artillery ammunition

Introduction

The method and its technical aspects of ammunition utilization mainly are conditioned by explosives properties. Comprehensive classification of above materials and consequently proper utilization methods, were discussed in previous authors' papers [2-4] which described practically all the area of the scope, e.g. utilization of explosive materials, detonators and powder charge [12, 13]. Mentioned utilization methods concern: burning, mechanical crushing, chemical treatment like nitro-groups reduction, chemical decomposition using molten salt or so-called biodegradation method that uses oxygen or no-oxygen bacterias and mineralization or joined method of above one [6, 12]. Thanks to explosives recycling, what in practice means secondary recristalization, there is a possibility to use such explosive materials for different industrial processes [6, 13], mostly for the mining [12, 13].

Generally, today methods of explosives removing from heavy-artillery ammunition and rockets rely on:

- overheated steam melting process,
- hot water washing-out process,
- combustion and firing process,
- mechanical removing,
- high-pressure water jet [8, 10] washing out or rarely with cryogenic jet [11, 15].

Such methods of ammunition deactivation have been used in the USA with a success [9, 16] for over twenty years [17, 18]. Besides that, the safety is the crucial factor during developing such technologies [1, 14]. Close techniques are in use in Europe lately [3, 5, 7]. Sometimes, such a purpose jets are characterized by complicated trajectories of its flow [4] achieved by a proper nozzle movement.

Some basic information connected to washing-out of explosive materials using high-pressure water jet is presented in the paper. Nowadays in Poland, it is actual problem mostly connected with ammunition storage. The problem results from ammunition past due but first its assortment change because of NATO procedures also adequate to normative of EU.

Research Stand

In order to carry out research of the most important physical factors occurred in the process of explosives washing-out from the heavy-artillery ammunition using high-pressure water jet, it is very important to analyze the dynamic influence of the high-pressure jet. The main experimental setup (Figure 1) used in the jet erosiveness investigation of such explosive materials is based on Hammelmann type HDP 164 pump system (Figure 2) and the new Hammelmann type HDP 483 pump system (Figure 3) giving the power of 750 KM.

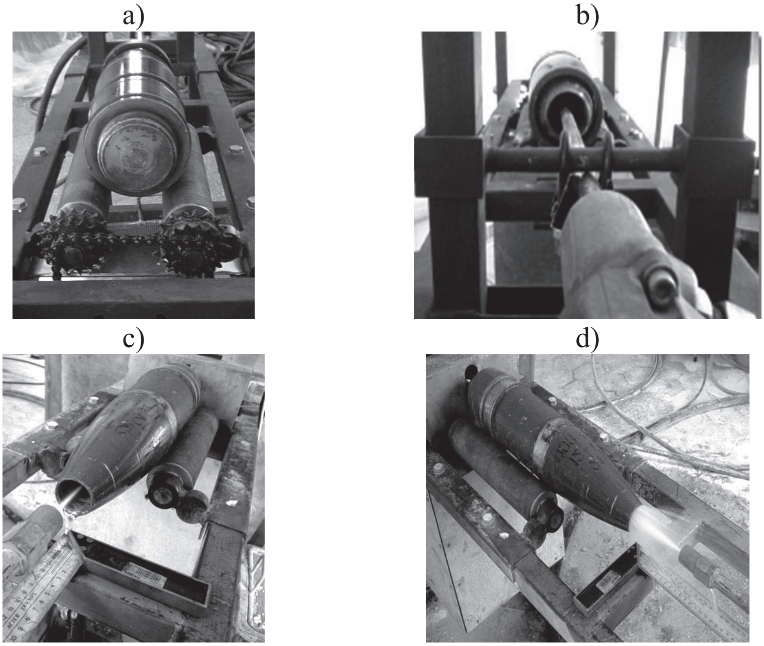

Figure 1. Test stand elements: a - ammunition drive, b - high-pressure system, c, d - different phases of high-explosives washing out process.

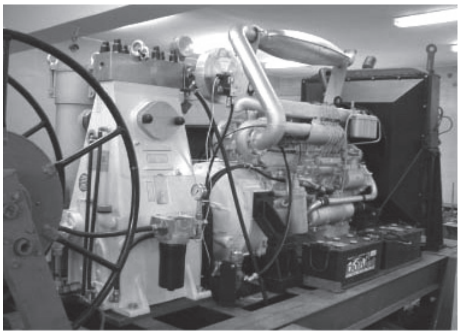

Figure 2. Ultra-high pressure Hammelemann HDP 164 pump system (p_{max}= 330 MPa, Q_{max}= 0.5 dm^3 s^{-1}).

Such test-stands produce the water-jet assuring the pressure parameters in the range of p = 20-330 MPa and water output Q_w= 0.5-2.6 dm^3 s^{-1}. It enables enough power to operate multi-stand unit for washing out dozen shells at the same time.

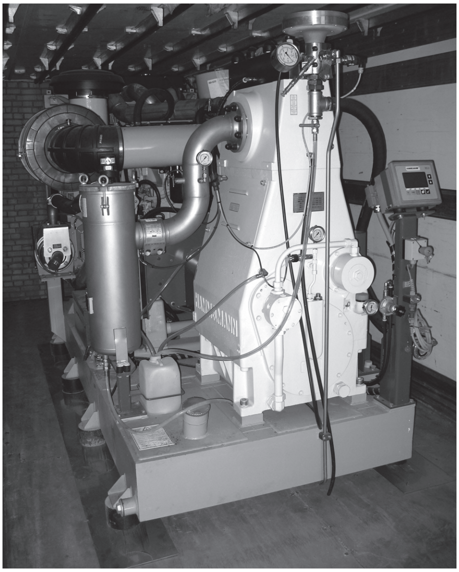

Figure 3. High-pressure Hammelemann HDP 483 pump system (p_{max}= 150 MPa, Q_{max}= 2.6 dm^3 s^{-1}).

Research Methods

The detailed characterization of all examined factors in the research method is too extensive. Most of those specific measurement techniques were developed and verified experimentally under the close hydrodynamic conditions during many own works. Therefore, this paper is limited mostly to description of the structure of research and its realization, which are presented below in the form of general schemes.

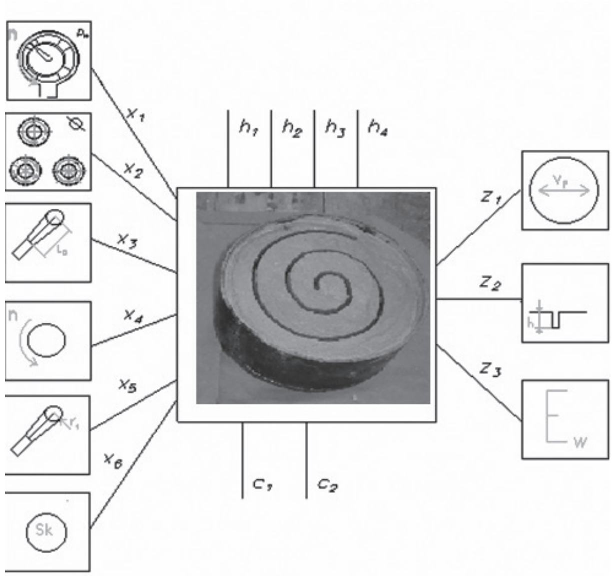

Figure 4. General schema of research object including explosives erosion process optimization.

Input data
x_1 – jet pressure
p = 30, 40, 50 MPa,
x_2 – nozzle diameter
d = 0.6, 0.8, 1.0, 1.5, 2.0 mm
x_3 – jet length
L_o = 10, 50, 100, 200 mm
x_4 – shell rotation speed n [rev min^{-1}]
x_5 – spraying radius r [mm]
x_6 – jet radial leap [mm rev^{-1}]

disturbance data
h_1 – jet pressure measurement error
h_2 – jet spraying angle inaccuracy
h_3 – jet pressure pulsation
h_4 – nozzle wear
constant data
c_1 – model explosives type
c_2 – jet type
output data
z_1 – jet feed rate v_p [mm min^{-1}]
z_2 – cut depth h [mm]
z_3 – process effectiveness E_w

The general schema of the examining object that let to establish objective test plan of explosives erosion process carried out in the aspect of its optimization, is presented in the Figure 4. As it shows, there are presented the most important details of examined factors of the erosion jet.

Similar more general in character schema of such process realized in order to define its erosion effectiveness during high-pressure washing-out is presented in Figure 5. Also here, the most important detail factors are presented in the aspect of cleaning process effectiveness taking into account important safety reason.

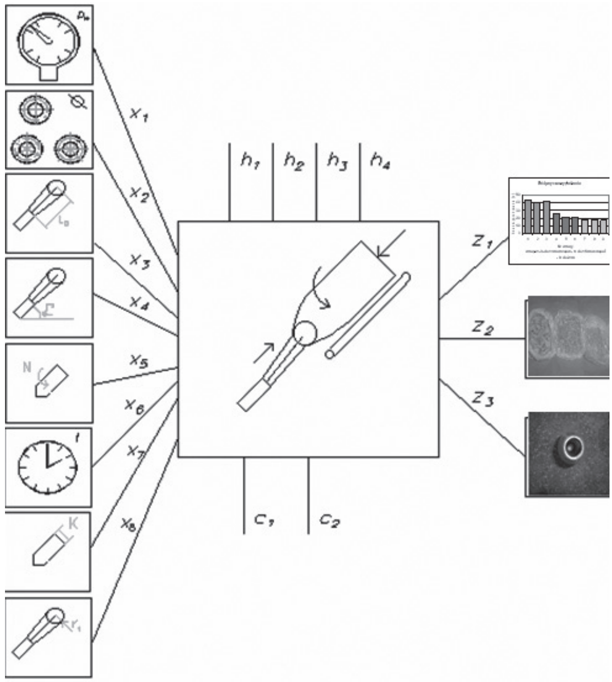

Figure 5. General schema of research object including HPWJ shells washing-out process effectiveness.

Input data

x_1 – jet pressure p = 30, 40, 50 MPa,

x_2 – nozzle diameter
d = 0.6, 0.8, 1.0, 1.5, 2.0 mm

x_3 – jet length
L_o = 10, 50, 100, 200 mm

x_4 – spraying angle

x_5 – shell rotation speed n [rev min^{-1}]

x_6 – spraying time t [s]

x_7 – shells caliber
k = 85, 100, 122, 125 mm

x_8 – jet spraying radius r [mm]

disturbance data

h_1 – jet pressure measurement error

h_2 – jet spraying angle inaccuracy

h_3 – jet pressure pulsation

h_4 – nozzle wear

constant data

c_1 – model explosives type

c_2 – jet type

output data

z_1 – process effectiveness E_w

z_2 – granulometrical fraction type f [mm]

z_3 – washed out surface quality J

Quality and morphology of explosive material granules and its surface erosion were assessed with different measuring instruments, including:

- stereo-optical microscope MBC-10,
- scanning electron microscope FEI Quanta 200 Mark II,
- 3D profilograph TalySurf type CLI 2000 made by Taylor Hobson.

Test Results

Below presented research concerns following most important problems: elaboration of HE materials substitute and its erosion conditions examining. It enables to determine the main effectiveness indicators as well as granulometric fractions of washed out HE material and its morphology.

Substitute of HE Material Elaboration

The first stage of research was directed to find out so-called substitute explosives material that ensures safety experimental process. Such a searching aim was to develop a sample material characterized by mechanical and technical properties e.g. grindability, hardness, impact resistance that would be close in character to typical explosive material. Over thirty of such composites were taken into consideration, consisted of different cement base compounds with addition of nitrocellulose lacquers, epoxy resins, linseed oil varnish also tree dust and potato flour as filling materials.

As a result of above procedure a following model of explosive material was established including: 28% of Portland cement, 8.5% of lime, 53% of sand quartz (#0.8-1.2 mm), 5% of wooden fluid and 4% of flour and 1.5% of residual compounds. Such a material is characterized by suitable mechanical properties adequate to TNT. The usage of above material results in safe processing of high-pressure water jet missile shells washing-out.

Eroding conditions of HE substitute

Main research was done for 85-125 mm caliber artillery ammunitions (Figure 6).

a) b)

Figure 6. Examples of tested missile shells (caliber range 85-125 mm): a – shells without fuse, b – shells fulfilled with high-explosives imitator.

Figure 7. Surface view of spiral samples.

During that, it was applied so-called spiral test presented in Figure 7. These were the basis for preparing kinematical nomograph of that process (Figure 8), which let consciously plan all the conditions of effective process. As it shows, increasing both rotation velocity of the missile and spiral radius, causes proportional increase of the jet move velocity regarding to model explosive material. Moreover, it shows real values of above kinematics relations and their influence on the cut depth. Typical eroded shape of above tests is presented in Figure 9.

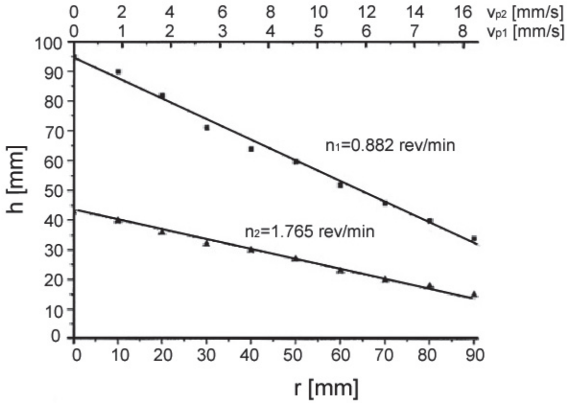

Figure 8. Influence of the missile rotary velocity (n) and spiral radius (r) on the feed rate (v_p) and explosives cut depth (h) defined during spiral tests.

Figure 9. Examples of explosive material washed out from artillery missile (p = 250 MPa, d = 0.7 mm).

Main Indicators of Process Effectiveness

However, those spiral tests are different from real conditions where high-pressure water jet injects through a front fuse hole and simultaneously flows out the same way including explosive material pieces. Such a process requires explosive material size reduction causing effectiveness decrease. Considering all those specific relations allows planning accurate process as well as properly evaluates its effects. Some exemplary effects of such HE substitute washing-out efficiency illustrated for 100 mm caliber shells using water jet pressured up to 50 MPa are presented in Figure 10.

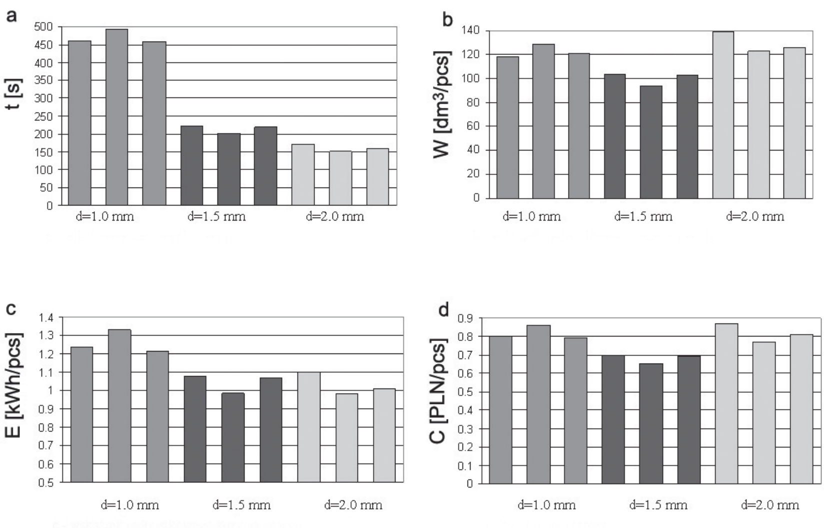

Figure 10. Different washing-out process rates indicated for missile cal. 100 mm and different nozzle types, p = 50 MPa, Lo = 50 mm. (a – time, b – effectiveness, c – energy consumption, d – costs).

An experimental analysis indicates that water nozzle diameter increase as well as water pressure resulting in explosive material washing-out effectiveness increase. For example (Figure 10a), using 1.0 mm diameter nozzle type causes the washing-out process time is twice longer than for 1.5 mm nozzle type. The shortest obtained washing out time in such conditions is equal 2 min. In turn, the rest process parameters e.g. water jet length or spraying angle, has no significant influence on washing-out process time. It is also worth notice that comparing 100 mm diameter missiles to 125 mm once, this time increases over 65% while 85 mm caliber cleaning time decreases of about 20%.

Moreover, one missile washing-out process needs at least 90-100 dm^3 of water (Figure 10b) while energy consumption is rather low average 1 kWh pcs^{-1} (Figure 10c). Basing on above data it should be stated that taking into consideration only water and energy rate, the minimum unit cost of explosives washing-out from 100 mm type missile doesn't exceed 0.70 PLN (Figure 10d).

Granulometric Fraction of Washed Out HE Substitute

One of the most important aspect of the washing-out process is its hydrodynamic straightly corresponding with established model material structure grinding. The overgrinding is an effect also of the inlet shell hole closely connected to its caliber (Figure 11). Therefore, too much overgrinding occurred mostly during sieve fraction analysis. Exemplary effects of above results are presented in Figure 12 showing out distribution of geometrical fraction analysis.

Usually such fraction was obtained using sieves in the range of No. f 12 (# >63 mm) to No. f 1 (# <0.125 mm) while smaller pieces in the form of sludge were recovered using sedimentation. Testing results showed that most often fraction of explosives were granules in the range of No. f 11 (# 31-63 mm) to No. f 8 (# 4-8 mm) while most often were sludge participation.

Figure 11. Typical examples of washed-out explosives fractions (p = 40 MPa, working head equipped with two nozzles d = 0.5 mm).

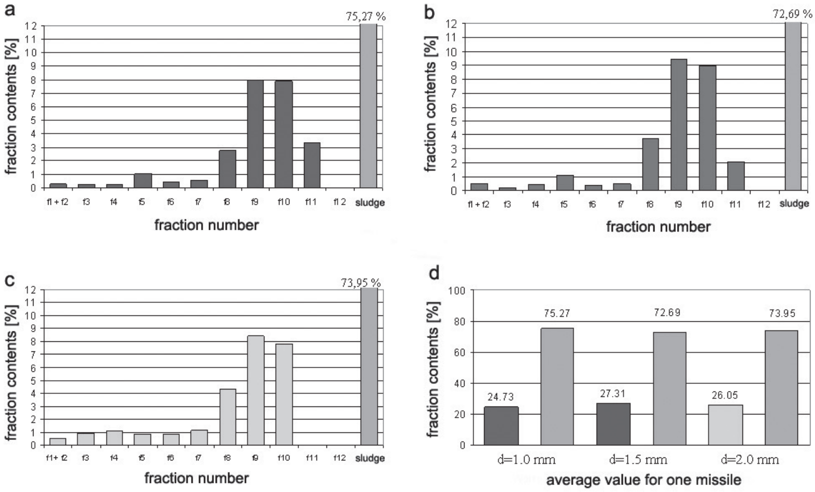

Figure 12. Percentage contents of explosive material granulometric fractions washed out from missile cal. 100 mm (p = 50 MPa, Lo = 50 mm) using following nozzle diameters: d = 1.0 mm (a), d = 1.5 mm (b), d = 2.0 mm (c) and comparison of grain and sludge fraction washed out from missile (d).

The Morphology of Washed Out HE Substitute

Granulometric fraction difference of explosive material together with its surface morphology has significant influence taking into account the method of its utilization. The morphology of HE substitute considerably depends on the size.

Generally, its surface is greatly developed, what can be seen in Figure 13 showing out the view and its microscopic structure as well as TalyScan's analytical pictures presented in Figure 14.

a) b) c)

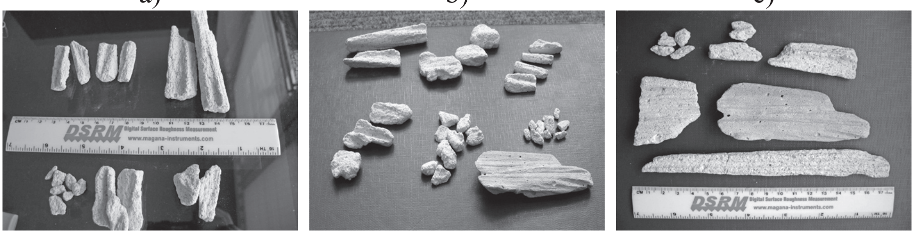

Figure 13. View of high-explosives imitator washed out from the missile: a – p = 50 MPa, b – p = 100 MPa, c – p = 150 MPa.

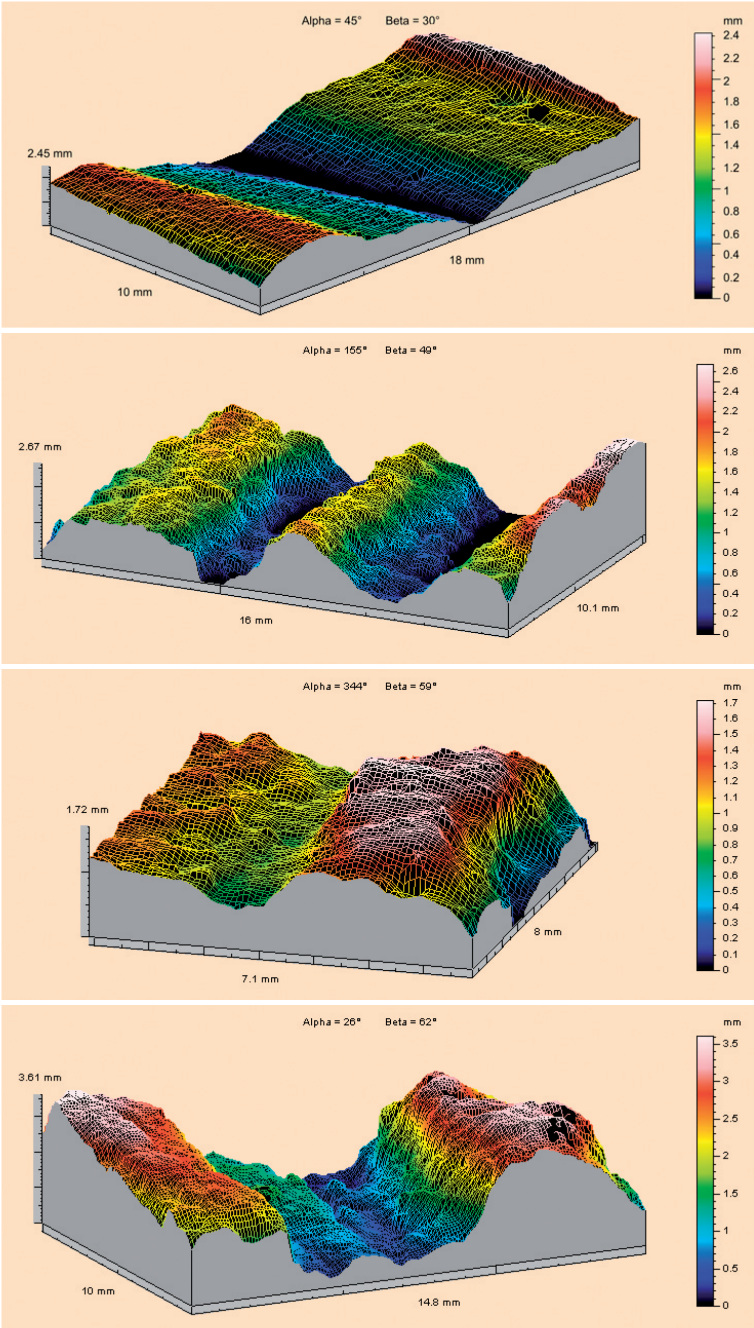

Figure 14. Exemplary morphology scans of washed out explosive materials.

All that testifies that model explosives material can be recycled. Some of those great particles could be directly used as an explosive. Recovered medium size fractions in the range of 4-31 mm could be use as elements of mining ammunition while the smallest ones for different explosives founding. Therefore, explosive material recovered from great caliber artillery ammunition using waterjetting technology can be applied to mining in a wide range.

Conclusion

So far, carried out research of HE substitute loosening and washing-out from great caliber artillery ammunition using waterjetting technology are distinguished by reliable repeatability. It enables good base for developing effective method of real ammunition disarmament. Conducted experiments of different erosion processes let also decrease process time increasing the same its effectiveness. It is especially connected to multi-stand technological system.

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