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Kakhovskyi, M.Yu.

Paton Electric Welding Institute, the NAS of Ukraine, Kyiv

INNOVATIVE TECHNIQUE FOR MECHANIZED UNDERWATER WELDING OF HIGH-ALLOY CORROSION-RESISTANT STEEL

The welding-repair technique using self-shielding flux-cored wire for underwater welding of high-alloy stainless steels of 18—10 type has been described. Its application enables minimizing the human intervention in the welding process under extreme conditions. The technique allows the welders to do repair works directly under water, without any additional assembly works.

Keywords: underwater welding, steel 12Cr18Ni10Ti, NPS, self-shielding flux-cored wire, FCAW, and coated electrodes.

The underwater welding is widely used for the repair and maintenance of equipment and pipelines for oil and gas production in the seabed, for the lift and repair of vessels, and for the manufacture of hydraulic elements, port facilities, and some power equipment.

Most elements of engineering equipment are made of low-alloy structural steels. However, given a low corrosion resistance of the low-alloy steels, the high-alloy steels are increasingly used in the manufacture of equipment due to their good corrosion resistance.

Among the main objects for the application of underwater welding of corrosion-resistant steels, there are the pools for storage of spent nuclear fuel (SNF) at nuclear power plants.

Having been removed from the reactor, the heat generating waste is kept in a pond for storing the SNF for 2–5 years, in order to decrease decay heat. The ponds are concrete reservoirs filled with fresh water having a depth of about 25 meters. The reservoirs are sheeted with high-alloy corrosion-resistant chromium-nickel steel, type 18-10, having a thickness of 3–5 mm. During loading/unloading of heat generating waste, the reservoir shell often suffer from mechanical damages. Untimely repair leads to a leakage of radioactive water, which can entail an environmental disaster.

The staff having a limited access to the equipment located in close proximity to the nuclear reactor because of high radiation intensity, remote-controlled facilities are mainly used for repair or routine maintenance. If a human labor is required the repair becomes much more complicated. Among possible solutions of this problem, there is the use of water environment as a natural barrier that reduces the impact of radiation on a diver while he is doing welding works.

For the first time, the man submersed under such conditions in the mid-70s when the first nuclear power plants in the US reached their midlife [1]. The underwater welding, for the first time, was used 10 years later, at the Pennsylvania NPP [2] equipped with boiling water reactors having a capacity of 1050 MW. In 1984, a visual inspec-

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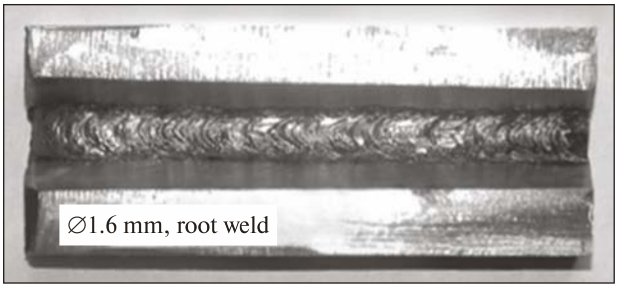


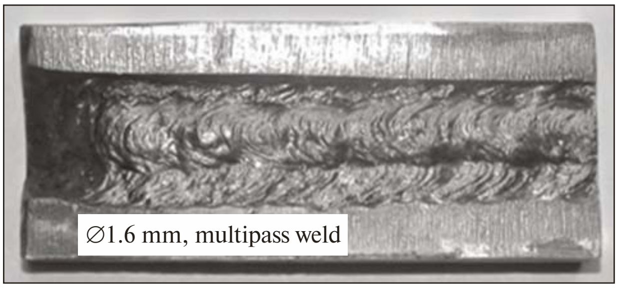


Fig. 1. Welds made by wet underground welding of high-alloy corrosion-resistant steel of 18-10 type

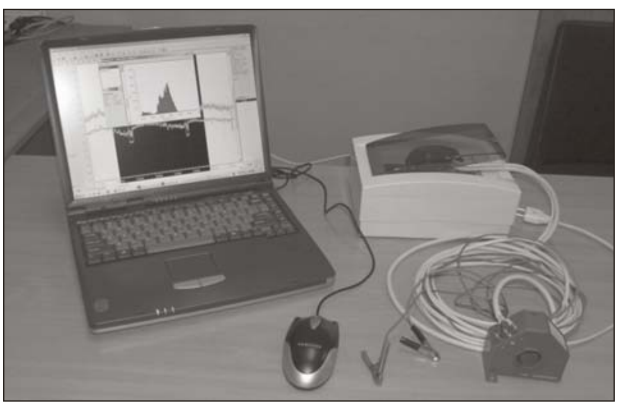


Fig. 2. Exterior appearance of ASP-19 welding analyzer

Table 1

Coated Electrodes for Underwater welding of High-Alloy Corrosion-Resistant Steels

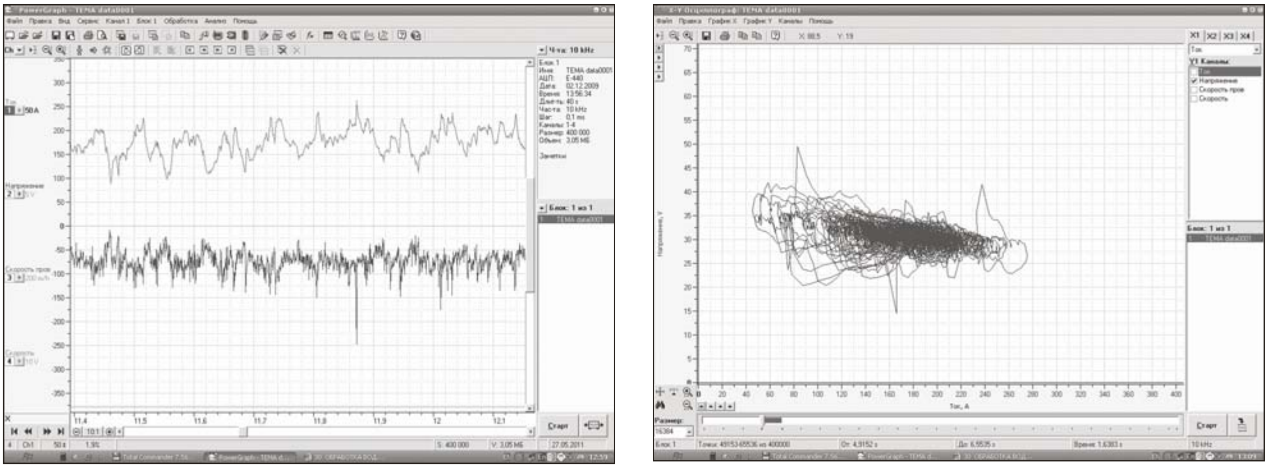
Electrode	Diameter, mm	Manufacturing country
Magnum MAG 0310x Eagle	3.2–4.0–4.8	USA
Broco Underwater SofTouch	3.2–4.0	USA
Surweld no.33	2.4– 3.2	USA
Speciality Welds Hammerhead	3.2	UK

tion made in the course of fuel charge revealed fatigue cracks in the housing of steam dryer. The radiation intensity on the surface of the housing was 1 BRE/h; at a distance of 46 cm it was measured as 0.5 BRE/h. To reduce the radiation dose it was decided to repair using a combined method, the room was filled with water and a diver did edge preparation. After this, water was poured out, with the defective part welded manually using a non-fusing electrode.

In 1987, during the fuel load another fatigue crack having a length 1400 mm was discovered in the steam generator casing [2]. The radiation intensity was very high even in the water environment (6 BRE/h, on the metal surface, and 1.5 BRE/h, at a distance of 30 cm). Under such conditions, the generator was repaired by underwater welding with coated electrodes. The room was filled with water, with diving welders doing the works underwater. The successful implementation of this project proved the suitability of the underwater welding with coated electrodes as an alternative to the traditional methods of repair.

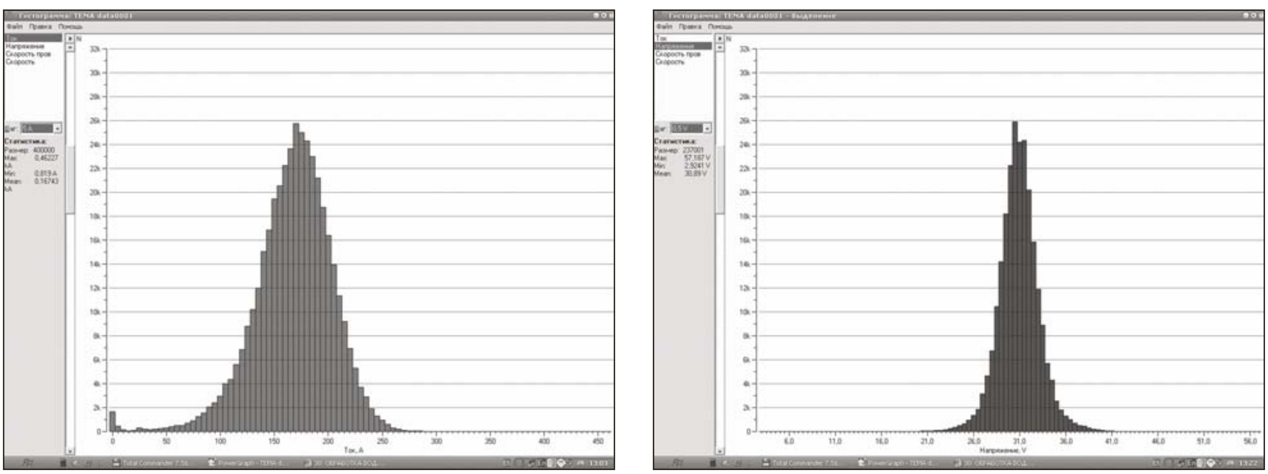
However, the technique required much time and resulted in significant losses as a result of interrupted production cycle of NPP and a significant adverse effect on the health diving welders who worked under high radiation intensity. It should also be noted that also, relatively high losses were reported for irregular (repeated) repairs caused by inadequate quality assurance of repair and insufficient reliability of equipment and skills of personnel [3]. Currently, the range of market materials for underwater welding of high-alloy corrosion-resistant steels includes only specialized coated electrodes (Table 1).

However, the manual arc welding with coated electrodes is characterized by lower effectiveness of welding and repair works, as well as by a lower quality of welds as compared with the mechanized and automated welding methods. In addition, the welding equipment globally tends towards automation (and mechanization) of welding process to completely eliminate human intervention, especially, in dangerous conditions.



a *b*

Fig. 3. Welding oscillograms (*a*) and voltage-current relationship flux cored wire welding (*b*)



a *b*

Fig. 4. Histograms of welding: current (*a*) and voltage (*b*)

Given the economic realities of nuclear power engineering with one hour of downtime costing half a million dollars [1], a more rapid technique for repair SNF storage ponds was required.

Wire welding in protective gases under water being impossible, the Paton Electric Welding Institute of the NAS of Ukraine started to develop a underwater welding technique using self-shielding flux-cored wire made of high-alloy corrosion-resistant steels of 18-10 type.

It should be noted that for the time being, in the world, there have no self-shielding flux cored wires of high-alloy corrosion-resistant steels for underwater welding, and this development is the first ever in the world.

The underwater welding differs from the air welding by some specific features. In the case of underwater welding, the arc burns in a closed volume of vapor bubble formed by the products of water dissociation, combustion and evaporation of fusible electrode and welded products [4]. The density of water exceeds 850 times the air density, the heat capacity of water is 4 times higher than that of air, and the thermal conductivity of water

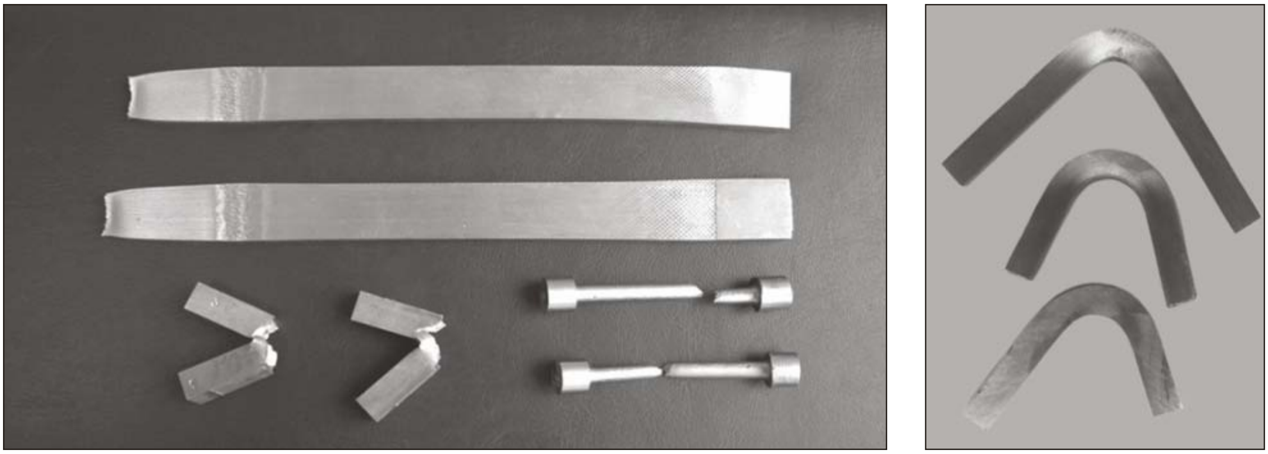


Fig. 5. Samples after mechanical tests

exceeds 25 times that of air [5]. Two types of compression (caused by cooling effect and by hydrostatic pressure of the liquid column) act on the arc burning in the aquatic environment [6]. It should also be noted that the cooling effect of water, high pressure, as well as the dissociation of water and its vapor lead to destabilization of arc burning, which leads to necessity to increase power consumption for supporting arc discharge as compared with the air welding [7, 8]. Under conditions of radioactive environment, the water as a natural barrier reduces the adverse impact of radiation on the human organism.

The underwater welding of high-alloy corrosion-resistant steels has several differences as compared with the welding of low-alloy structural steels. In the low-alloy steels, the oversaturation of weld metal with hydrogen leads to the formation of welding defects and worsened mechanical properties of the welds, while the solubility of hydrogen in the austenite metal is rather high (55–60 $cm^3/100$ g) and, usually, is within the solubility limits [4].

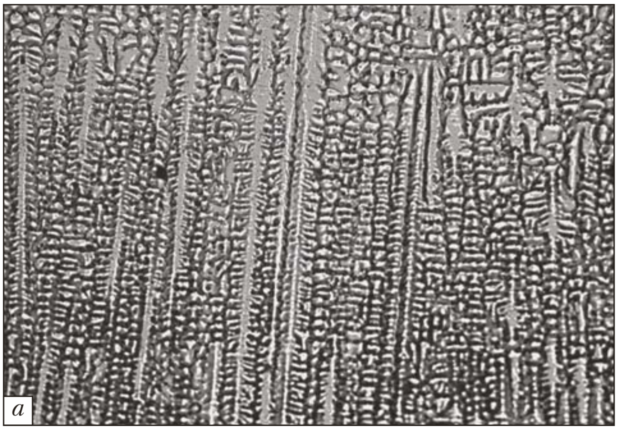
For the underwater welding of corrosion-resistant steels, the priority is to ensure a reliable protection of weld metal from oxidative impact of environment. While interacting with the weld metal, both at the stage of drop and at the stage of pool, oxygen stimulates the burn out of active alloying components and may manifest itself as oxide inclusions that adversely affect the mechanical properties of the weld metal and cause defects, such as pores. The oxygen content in the weld metal reaches 0.25 wt. % [4].

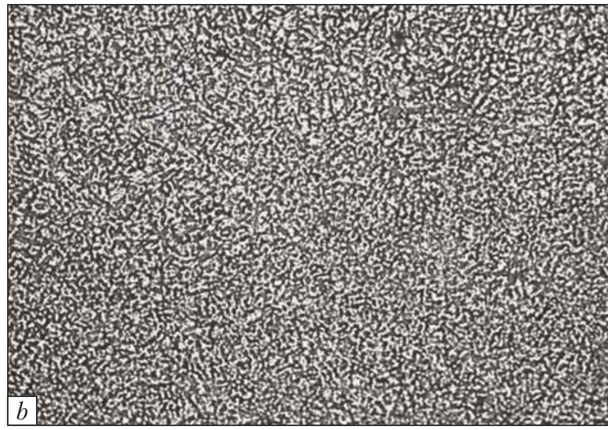
Fig. 1 shows the appearance of the welds made during underwater welding using a wire

Table 2

Chemical Composition of Weld Metal for Wet Underground Welding and for Air Welding

Environment	Chemical composition of weld Metal, wieght %							
	C	Si	Mn	Cr	Ni	Nb	S	P
Air	0.06	0.52	1.83	21.83	9.5	0.30	0.015	0.025
Water	0.04	0.32	1.23	20.90	9.4	0.21	0.018	0.022
GOST 10052-75	0.05– 0.12	< 1.3	1–2.50	18–22.00	8– 10.50	0.70–1.30; at least, 8 C	< 0.020	< 0.030





Puc. 6. Weld metal microstructure: air welding (*a*) and underwater welding (*b*)

of high-alloy corrosion-resistant steel of 18-10 (12X18H10T) type. Welding was performed with a self-shielding flux cored wire having a diameter of 1.6 mm at a direct current of reverse polarity using a VDU-601 rectifier as power source for Ud = 32–34 V; Iw = 140–160 A.

The wires were tested in a special welding pond filled with tap water. The melting and transfer of electrode metal and arc stability were evaluated using an ASP-19 welding processes analyzer (Fig. 2). As one can see from the oscillograms of voltage and current, from the voltage-current characteristics (Fig. 3), and from the current and voltage histograms (Fig. 4) built using Power Graph Professional v.3.3., no short circuits are reported and the welding processed shows a good stability of the arc.

The results of chemical analysis show that the weld metal composition corresponds to a given type of doping 06H20N9H2B according to GOST 10052-75. The content of ferrite phase in the weld metal was estimated by volumetric magnetic method using an MF-10i ferrite meter. According to GOST 9466-75, the ferrite content in the weld metal for type 06H20N9H2B should range within 4–10 wt. %. The structure of weld metal is austenite + 6 % α-phase. The susceptibility of welded joints to intergranular corrosion was tested by

Table 3

Gas Content in Weld Metal for Wet Underground Welding and for Air Welding

Environment	Gas content in weld metal		
	weight %		$cm^3/100$ g
	[N]	[O]	[H]
Air	0.06	0.05	10.5
Water	0.03	0.07	27.0

Note. The Table contains averaged data of three measurements of hydrogen and oxygen content in MI 99 samples cut from the last layer of deposit.

Table 4

Mechanical Properties of Metal and Welded Joint for Underground Welding of 18-10 High-Alloy Corrosion Resistant Steel Using PP-ANV-25 Self-Shielding Flux Cored Wire at a Temperature of 20 °C

Yield stress $\sigma_{0,2}$, MPa	Ultimate tensile strength $\sigma_в$, MPa	Relative elongation δ, %	Contraction ratio Ψ, %	Impact hardness $a_к$, J/cm²	Angle of bend, degree $R = t$
350.8	623.3	25.7	28.7	90.3	68...103

AM method, according to GOST 6032 2003. The sample analysis showed no signs of intergranular corrosion.

The results of analysis of the weld metal chemical composition for the underwater welding (see Table 2) show a good correspondence with the data for the air welding using a self-shielding flux-cored wire.

The content of hydrogen, oxygen, and nitrogen was determined for the last joint of seven-layer deposit. The gas content in the weld metal is given in Table 3.

The mechanical properties of the weld metal and the joint are presented in Table 4; the appearance of samples is showed in Fig. 5.

The results of mechanical tests meet the Class B requirements of ANSI/AWS D3.6 international standard for underwater welding.

The metallographic studies of weld metal showed that for the underwater welding, the total number of nonmetallic inclusions increased almost 2 times, but they were dispersed and evenly distributed over the cross section of the joint. The weld metal structure is more fragmented as the grain size decreases more than 3 times (Fig. 6).

The data presented in [9] show that the technique of mechanized underwater welding with self-shielding flux-cored wire (PP-ANV-25) enables reducing the time of welding repair works and cheapens the total cost of repairs 2.63 times in comparison with the manual arc welding with coated electrodes.

CONCLUSIONS

1. The test results showed that the world pioneer self-shielding flux cored wire (PP-ANV-25) ensures the required chemical composition and mechanical properties according to GOST 10052-75 and meets the class B requirements of ANSI/AWS D 3.6-92 international standard for underwater welding.

2. The new flux cored wire PP-ANV-25 enables raising the productivity and quality of underwater welding and repair works and profiting from reduced downtime of the facility repaired.

3. The application of mechanized welding technique using self-shielding flux cored wire makes it possible to reduce adverse effect on diving welder due to reduction of time spent in radioactive environment, and, in the future, to automate the process and to exclude any human intervention in the welding of critical structures under extremely dangerous conditions.

REFERENCES

1. R. Hancock. Underwater nuclear. *Welding Journal*. 2003, N9: 48—49.
2. J.E. O`Sullivan. Wet underwater weld repair of Susquehanna unit 1 steam dryer. *Welding journal*. 1988, N6: 19—23.
3. Podushka M.N., Rystenkov A.N., Skalozubov V.I., Kovrizhkin Ju.L. Proekt i perspektivy programmy optimizacii planirovanija i upravlenija remontnyh kampanij jenergoblokov Zaporozhskoj AJeS. *Problemi bezpeki atomnih elektrostancij i Chornobilja*. Vip. 15, 2011: 35—41 [in Russian].
4. Avilov T.I. Issledovanie processa dugovoj svarki pod vodoj. *Svarochnoe proizvodstvo*. 1958, N5: 12—14 [in Russian].
5. Kononenko V.Ja. *Podvodnaja svarka i rezka*. Kyiv: Universitet Ukraina, 2011 [in Russian].
6. Madatov N.M. *Podvodnaja svarka i rezka metallov*. Leningrad: Sudostroenie, 1967 [in Russian].
7. Leskov G.I., Potiha O.M. Jenergeticheskie parametry dugi v uslovijah gidrostaticheskogo davlenija do 5 MPa. *Avtomat. svarka*. 1999, N1: 15—18 [in Russian].
8. Leskov G.I. Jenergeticheskie harakteristiki dugi so stal'nymi jelektrodami v atmosfere vodoroda. *Avtomat.svarka*. 1993, N10: 3—5 [in Russian].
9. Kahovs'kyj M.Ju. Poroshkovyj samozahysnyj drit dlja pidvodnogozvarjuvannjavysokolegovanoi'korozijnostijkoi' stali 12 H18N10T. *Molodyj vchenyj*. 2014, N11: 12—15 [in Ukrainian].

М.Ю. Каховський

Інститут електрозварювання ім. Є.О. Патона
НАН України, Київ

ІННОВАЦІЙНА ТЕХНОЛОГІЯ МЕХАНІЗОВАНОГО МОКРОГО ПІДВОДНОГО ЗВАРЮВАННЯ ВИСОКОЛЕГОВАНОЇ КОРОЗІЙНОСТІЙКОЇ СТАЛІ

Викладено результати проведення зварювально-ремонтних робіт самозахисним порошковим дротом при мокрому підводному зварюванні високолегованих корозійностійких сталей типу 18-10. Застосування даної технології дає змогу зменшити участь людини в процесі зварювання в екстремальних умовах. Практична цінність цієї технології полягає в можливості виконання зварювально-ремонтних робіт безпосередньо під водою без будь-яких додаткових монтажних робіт.

Ключові слова: мокре підводне зварювання, сталь 12Х18Н10Т, АЕС, самозахисний порошковий дріт, FCAW, покриті електроди.

Н.Ю. Каховский

Институт электросварки им. Е.О. Патона
НАН Украины, Киев

ИННОВАЦИОННАЯ ТЕХНОЛОГИЯ МЕХАНИЗИРОВАННОЙ МОКРОЙ ПОДВОДНОЙ СВАРКИ ВЫСОКОЛЕГИРОВАННОЙ КОРРОЗИОННОСТОЙКОЙ СТАЛИ

Изложены результаты проведения сварочно-ремонтных работ самозащитной порошковой проволокой при мокрой подводной сварке высоколегированных коррозионностойких сталей типа 18-10. Применение данной технологии позволяет уменьшить участие человека в процессе сварки в экстремальных условиях. Практическая ценность этой технологии заключается в возможности выполнения сварочно-ремонтных работ непосредственно под водой без каких-либо дополнительных монтажных работ.

Ключевые слова: мокрая подводная сварка, сталь 12Х18Н10Т, АЭС, самозащитная порошковая проволока, FCAW, покрытые электроды.

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