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Satbayev University

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ИЗВЕСТИЯ

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РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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DEVELOPMENT OF AIR-PLASMA TECHNOLOGY FOR HARDENING CUTTING TOOLS BY APPLYING WEAR-RESISTANT COATINGS

Abstract. This work describes an air-plasma installation and a method of hardening cutting tools by applying wear-resistant coatings. There are shown the results of commissioning of an air-plasma installation and the results of calculation and evaluation of the performance of the developed plasmatron. A plasmatron was made in order to reduce the heat load and improve the quality of the sprayed layer of the plasmatron operating life, as well as this plasmatron include a cooled anode, a swirl unit, an interelectrode insert, and a cathode. There was performed thermal analysis of the plasmatron design using the SolidWorks finite element method. The analysis results showed that the elements of water and gas communications of the plasmatron withstand pressure with a nominal value of 2.5-3 atm. at a power of 25 kW. The results of a study of the structure and properties of TiN and SiC coatings are shown. The results of tribological tests showed that TiN and SiC coatings can improve the tribological properties of P6M5 high-speed steel.

Key words: coating, air-plasma spraying, structure, titanium nitride, plasmatron, silicon carbide.

Introduction. One of the further development tasks of mechanical engineering is to increase the service life of metal-cutting tools (drills, taps, reamers, etc.) [1]. As it is known [2-6], modification by high-energy exposure is an effective means of increasing the service life and improving the physicomechanical and operational properties of the surface of cutting tools. Improving the operational properties of the cutting tool is largely determined by the hardening technology. Widely known ion-plasma hardening technologies by applying nitride, carbonitride coatings require the use of special expensive equipment and are economically feasible only for mass and large-scale production [7-10].

In practice, such restrictions do not occur when working surfaces hardening of the tool by the air-plasma method [11-13]. In addition, the use of air as an active plasma-forming medium greatly simplifies the installation for spraying and increases the safety of work and reduces the cost of coatings. However, the phase-structural transformations and the physical mechanisms of the formation of coatings are still insufficiently studied in spite of some successes achieved in the practical implementation of air-plasma processes. In addition, studies on the effect of air-plasma hardening on the structure and properties of high-speed steels have practically not been carried out [14-18]. Therefore, the method has not yet been implemented in tool production. In this regard, the task in this work was to develop a technology for hardening cutting tools by applying wear-resistant coatings on the working surface by the air-plasma method.

The authors of this work developed and manufactured an installation for air-plasma spraying of coatings, which consists of a plasmatron, an inert gas supply system for argon and air, an inverter type 500 A power source with an open circuit voltage of 60 V, and an autonomous cooling system for the plasmatron. Figure 1 shows a general view of an installation for air-plasma coating.

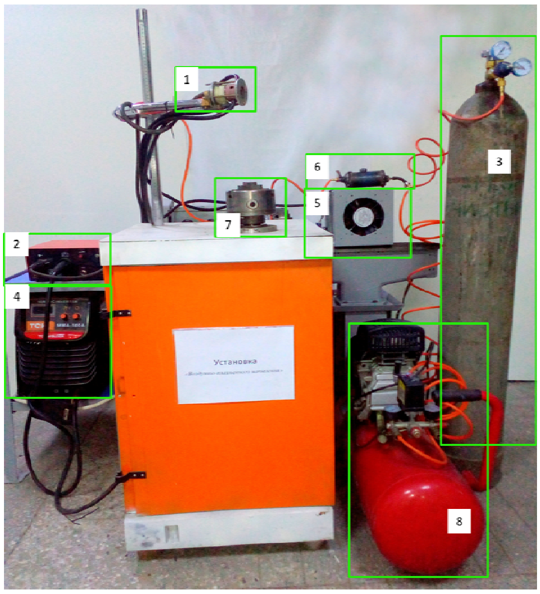

Figure 1 – Installation for air-plasma coating:
1 - plasmatron, 2 - process control unit, 3 - gas supply cylinder,
4 - power supply system, 5 - cooling system, 6 - bifurcated powder
supply channel with expansion barrel, 7 - sample holder, 8 - compressor

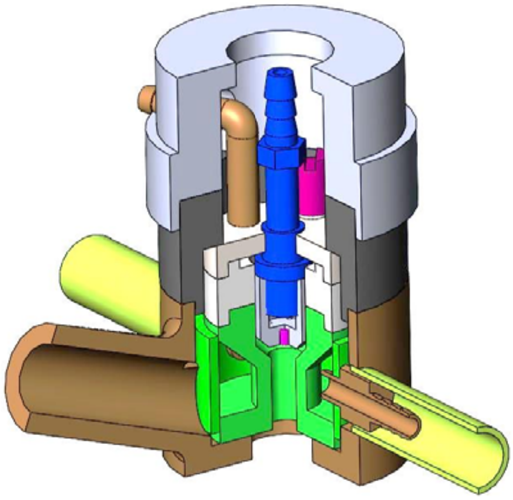

Figure 2 –
3D model of a plasmatron

One of the problems in the field of air-plasma technology is the short life of the plasmatron. In this regard, we set the task of increasing the life of the plasmatron and carried out a number of works. We developed a plasmatron design on the bases of study of existing plasmatron models for APS, which consists of the following parts: anode, cathode, interelectrode ceramic insert, electricity, insulating ceramic nodes, powder, coolant, plasma forming gas, and carrier gas supply nodes. Argon and air are used as the working gas in the developed plasmatron design. The plasmatron body is cooled by water flow through a special cooling channel through the coolant supply fitting. Figure 2 presents a 3D model of the developed plasmatron. The developed plasmatron design differs from existing plasmatron for APS in that the outlet openings in the nozzle are made in the form of rectangular tapering-expanding channels. This gives an additional acceleration of the plasma flow at the exit of the nozzle.

A thermal analysis of this circuit was performed using the SolidWorks finite element method in order to evaluate the performance of the plasmatron [19]. Figure 3 presents the color differentiation a) the temperature of the solid; b) temperature of the fluid; c) flow rate. The analysis results showed that the elements of water and gas communications of the plasmatron withstand pressure with a nominal value of 2.5-3 atm. at a power of 25 kW. Thus, the developed design of the plasmatron fully satisfies the condition of air-plasma spraying.

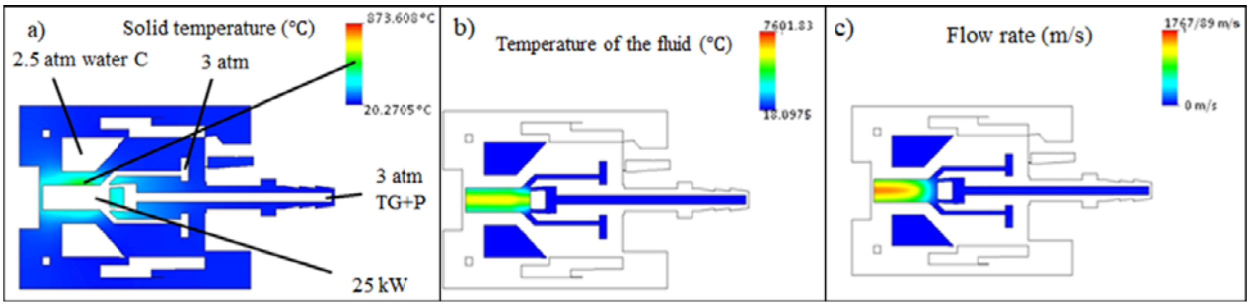

Figure 3 – Results of thermal analysis (TG - transporting gas, C - coolant, P - powder):
a) solid temperature; b) temperature of the fluid; c) flow rate

We have made a prototype plasmatron on the bases of the developed plasmatron designs. Full-scale tests of the plasmatron were carried out at various capacities. The results showed that the 12X18H10T stainless steel anode material begins to break down at high powers (20 kW) and molten areas are observed on the surface, as well as areas sprayed with molten powders that were used for spraying. In addition, the fluoroplastic plasmatron case also became brittle after 3 hours of plasmatron operation. In this connection, we modernized the plasmatron, in particular, we developed a system for introducing powder into the plasma (swirl unit), which rotates the anode spot and prevents local burning of the anode, as well as replaced the anode material and the case material with copper (copper of M0 grade), which has high heat and electrical conductivity compared to steel. The construction design of the swirl assembly is developed on the basis of finite element modeling.

These changes allow to prevent the local burning of the anode, poor passability of the powder through the spray channels and heating of the plasmatron body, which increased the durability of the plasmatron nodes and resources of plasmatron work. Also, full-scale experiments of the plasmatron showed that the introduced changes made it possible to stably apply coatings without destroying the plasmatron nodes. Figure 4 shows a general view of the plasmatron before and after modernization.

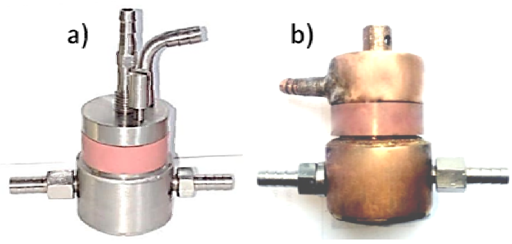

Figure 4 – General view of the plasmatron before (a) and after modernization (b)

The installation was equipped with a non-contact "arc excitation" system based on the high-frequency current oscillator OSSD 500 in order to ensure more stable arc excitation. Figure 5 shows a non-contact "arc excitation" system and a matching circuit between the power source and the oscillator. As a result, it became possible to automatically start the plasmatron with a gap between the anode and electrode of up to 5 mm.

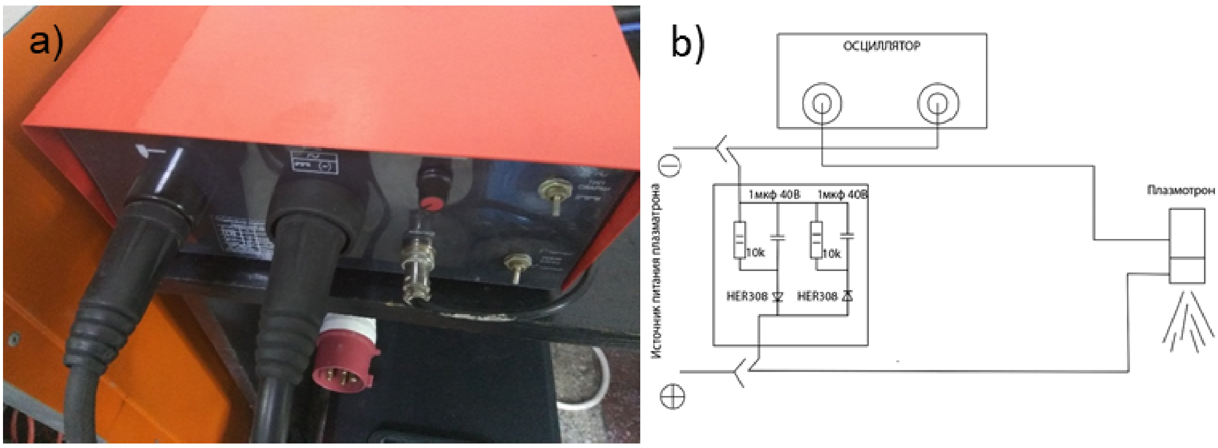

Figure 5 – The system of non-contact "arc excitation" (a) and the matching scheme of the power source and oscillator (b)

The developed technology and installation for air-plasma spraying can be carried out in the conditions of a small thermal section of single and small-scale production, pilot and repair enterprises with minimal costs for equipment, auxiliary materials and electricity, with ease of implementation and maximum processing efficiency. An experiment on the production of carbide and nitride coatings on the surface of high-speed steels was carried out on the developed air-plasma spraying (APS) installation, as well as laboratory experiments of the coatings were carried out.

Material and methods of research. P6M5 high-speed steel was chosen as the research material. The experiments on obtaining coatings based on SiC and TiN were carried out in the following mode: moving speed 2-30 mm/s, the distance between the plasmatron and the product 45-55 mm, the diameter of the spray spot 10-25 mm. The temperature of the parts during spraying does not exceed 150-200 °C. Preliminary sandblasting with dry corundum was carried out to improve adhesion (at an air pressure of 0.3-0.6 MPa, the distance from the nozzle exit of the jet-abrasive gun to the work surface is 80-100 mm).

The method of studying friction wear resistance by using a device that allows measuring the sliding friction force in alternating motion was applied in order to evaluate the tribological characteristics of carbide and nitride coatings obtained by the APS method [20]. A SiC ball with a diameter of 4 mm and a hardness of H_V = 2800 mm was tightly pressed (with F_n gain) to the surface of the sample. The system consists of two supporting bodies moving in the same direction. The system that moves the plate consists of two load-bearing bodies moving in the same direction, which allows the friction force to be divided. The drive was an electric drive consisting of a stepper motor and a helical gear. The power of movement was transmitted from a larger trolley to a smaller one using a strain gauge. The system allowed the installation of a fixed displacement of the steel plate relative to the ball with a certain speed Vs and displacement S, the force causing the FT motion was recorded with a frequency of 10 Hz. The path length was 12 m, speed 2 cm/s, load 5 N.

The experiments results of obtained coatings. Using these powders, coatings were obtained on the surface of P6M5 high-speed steel under various conditions. Coating modes are shown in table.

Modes of air-plasma coating from TiN and SiC

Powder	TiN			SiC		
№	1	2	3	4	5	6
Arc current, A	135	160	175	135	150	250
Coating Thickness, μm	28	23	14	21	89	20

There were carried out metallographic research of transverse sections of coated samples. Figure 6 presents a fragment of the microstructure of the transverse section of SiC and TiN coatings during air-plasma spraying.

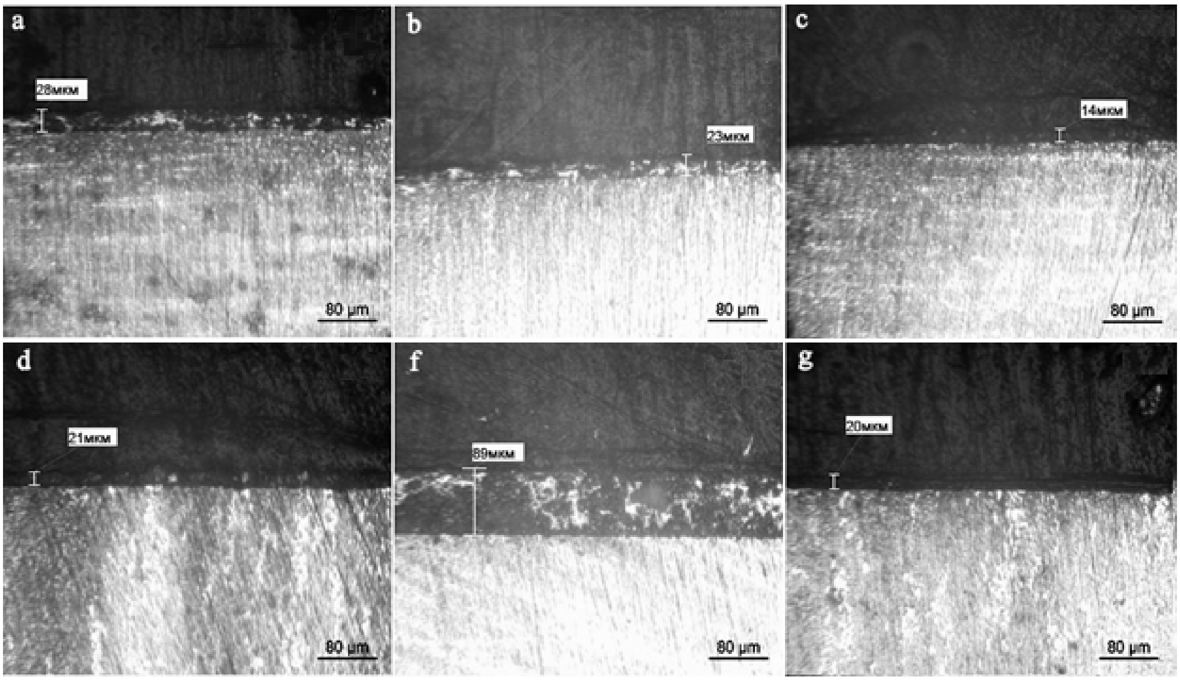

Figure 6 – Image of the cross section of the sample coatings with TiN and SiC powders:
a) TiN at 135 A, b) TiN at 150 A, c) TiN at 175 A, d) SiC at 135 A, f) SiC at 150 A, g) SiC at 175 A

Figure 7 shows the friction coefficient of the sample at a normal force of 5 N and a mutual displacement velocity of 0.94 cm/s, the value of the friction coefficient is in the range from 0.2 to 0.8 μ. TiN coatings are characterized by a more stable running-in period: a friction coefficient of ~ 0.2 μ. The running-in period of 7 m is already 0.8 μ for the P6M5 high-speed grease substrate. The friction coefficient was 0.2 μ, and the substrates - 0.3 μ for SiC coatings.

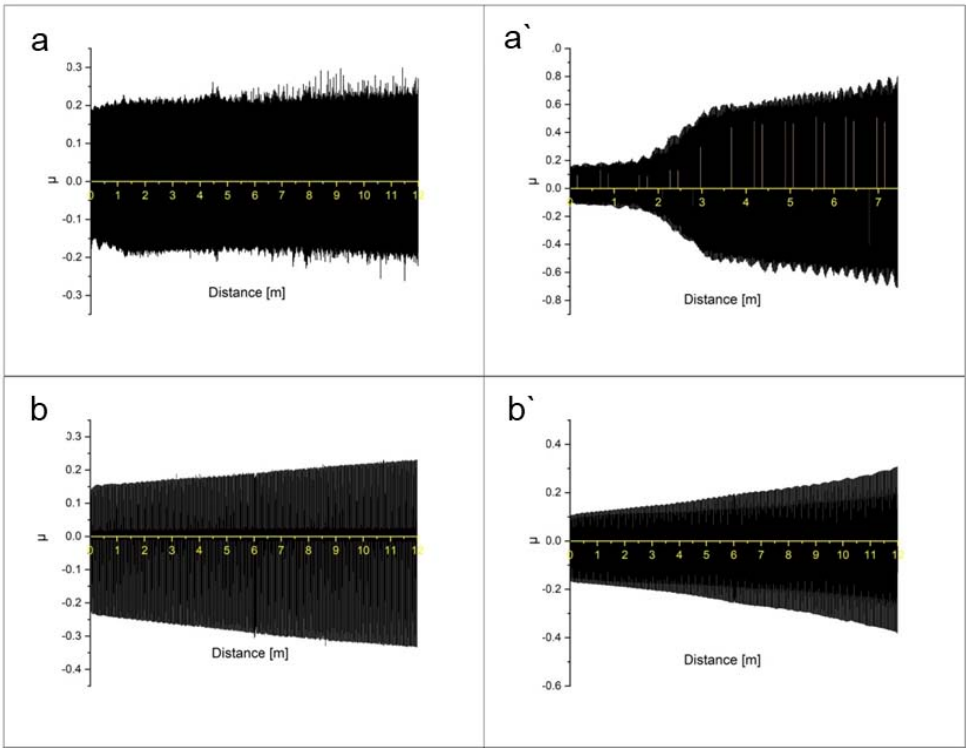

Figure 7 – The friction coefficient of the sample:
a) TiN (135 A), a') substrate, b) SiC (250 A), b') substrate

Figures 8, 9 present the diffraction patterns of the substrate, the initial powder, and the resulting TiN and SiC coatings. The phase composition of coatings on the surface of P6M5 steel corresponds to the composition of the initial powders. In this case, substrate reflections appear on the diffractograms of the coated samples. Thus, X-ray phase analysis showed that after deposition new phases are not formed both on the coating and in the substrate, which confirms the low temperature of the substrate heating during the deposition process. This, in turn, confirms the absence of softening of the substrate.

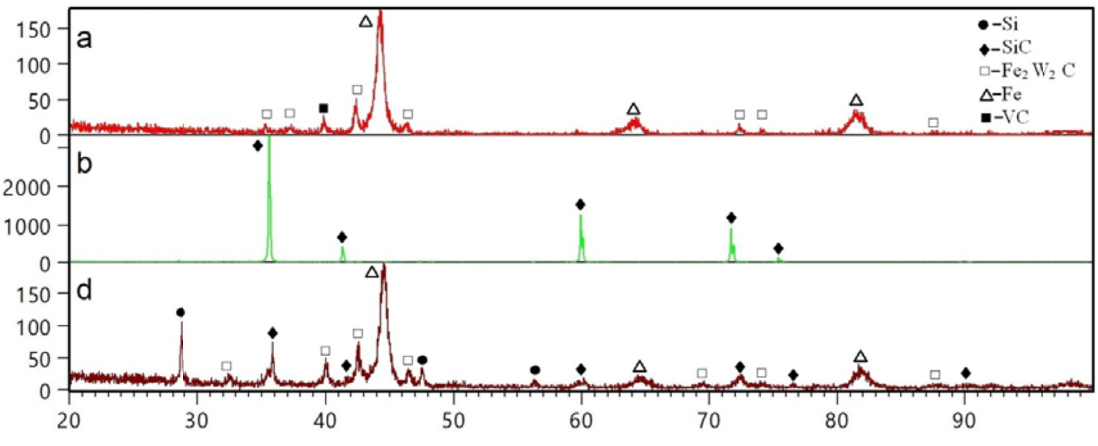

Figure 8 – Diffraction pattern of samples: a) P6M5, b) SiC powder, d) SiC coatings

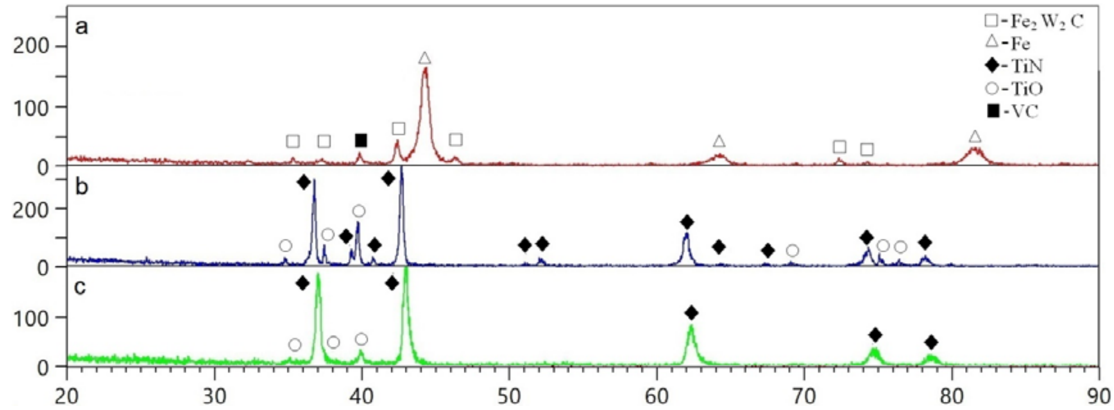

Figure 9 – Diffraction pattern of samples: a) P6M5, b) TiN powder, c) TiN coatings

Conclusion. Analyzing the results, we can draw the following conclusions:

- An installation has been developed for air-plasma spraying, which consists of: a plasmatron, an inert gas supply system for argon and air, an inverter type 500 A power source with an open circuit voltage of 40 V, and an autonomous cooling system for the plasmatron.

- A plasmatron has been developed, which consists of a cooled anode, a swirl unit, an interelectrode insert, and a cathode. The advantage of the developed plasmatron is that the outlet openings in the nozzle are made in the form of rectangular tapering-expanding channels, as well as the anode is made completely welded and its surface has a radiator profile that will allow disassembling and assembling the plasmatron during repair work without compromising its quality.

- It has been determined that TiN and SiC coatings can improve the tribological properties of high-speed steel, in particular, the friction coefficient decreases by a factor of 2–3, and the wear resistance increases by a factor of 1.5 times.

Thus, the conducted research have shown the promise and feasibility of using the developed technology for increasing the wear resistance of cutting tools.

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ТОЗУҒА ТӨЗІМДІ ЖАБЫНДАРДЫ ЖАҒУ ЖОЛЫМЕН КЕСКІШ ҚҰРАЛДАРДЫ БЕРІКТЕНДІРУДІҢ АУА-ПЛАЗМАЛЫҚ ТЕХНОЛОГИЯСЫН ӘЗІРЛЕУ

Аннотация. Машина жасауды одан әрі дамыту міндеттерінің бірі – металл кескіш құралдардың (бұрғы, метчик, қашау және т.б.) қызмет ету мерзімін арттыру. Жоғары қуатты модификация – бұл қызмет мерзімін ұлғайтудың және кесу құралдарының бетінің физикалық, механикалық және пайдалану қасиеттерін жақсартудың тиімді құралы. Кескіш құралдың жұмыс істеу қасиеттерін арттыру көбінесе өңдеу технологиясымен анықталады

Осыған байланысты бұл жұмыста тозуға төзімді жабындарды жағу жолымен кескіш құралдарды беріктендірудің ауа-плазмалық технологиясын әзірлеу міндеті қойылды. Осы мақсатта ауа-плазмалық тозаңдату қондырғысы (АПТ) жасап шығырылды. Қондырғының негізгі сипаттары плазмотрон, аргон мен ауаны инертті газбен қамтамасыз ету жүйесінен, кернеуі 60 В ашық инвертор түріндегі 500 В қуат көзінен, автономды плазмотронды салқындату жүйесінен тұрады. Плазмотронның әзірленген конструкциясында жұмыс

газы ретінде аргон мен ауа пайдаланылады. Плазмотронның жұмысқа қабілеттілігін бағалау мақсатында SolidWorks бағдарламалық ортасында осы схемаға термиялық талдау жүргізілді.

Доғаның тұрақты қозуын қамтамасыз ету үшін қондырғы ОССД 500 жоғары жиілікті ток осцилляторының негізінде байланыссыз «доғалық қозу» жүйесімен жабдықталған. Әзірленген ауа плазмалық тозаңдату қондырғысында карбидті және нитритті жабындарды алу бойынша эксперимент жүргізіліп, зерттеулер жасалды. Төсеніш зерттеу материалы ретінде Р6М5 жылдам кесетін болат таңдалды. SiC және TiN негізінде жабындарды алу бойынша эксперименттер мынадай режимде жүргізілді: ауыстыру үлгісінің қозғалу жылдамдығы – 2-30 мм/с, плазмотрон мен үлгі арасындағы қашықтық – 45-55 мм, тозаңдату дақтарының диаметрі – 10-25 мм. Тозаңдату кезінде бөлшектерді қыздыру температурасы 150-200 °С-тан аспайды. Адгезияны жақсарту үшін құрғақ корундпен алдын ала құм бүріккіш арқылы өңдеу жүргізілді (ауа қысымы – 0,3-0,6 МПа, ағысты-абразивті сопладан бетке дейінгі қашықтық 80-100 мм құрайды).

АПТ әдісімен алынған карбид және нитридті жабындардың трибологиялық сипаттамаларын бағалау мақсатында ауыспалы қозғалыстағы үйкеліс күшін өлшеуге мүмкіндік беретін құрылғының көмегімен үйкеліс кезінде тозуға төзімділікті зерттеу әдісі қолданылды. Жүріс ұзындығы – 12 м, жылдамдығы – 2 см/с, жүктеме – 5 Н.

Жабыны бар үлгілердің көлденең қималарына металлографиялық зерттеу жүргізілді. Мақалада 5 Н қалыпты жүктемедегі үлгінің үйкеліс коэффициенті және 0,94 см/с өзара жылжу жылдамдығы көрсетілген, үйкеліс коэффициентінің мәні 0,2-ден 0,8 μ дейінгі аралықта болады. TiN жабындарына тұрақты жұмыс істеу кезіндегі үйкеліс коэффициенті ~ 0,2 μ. Ал тез кесетін болат Р6М5 үшін үйкеліс коэффициенті 0,8 μ құрайды. SiC жабындары үшін үйкеліс коэффициенті 0,2 μ құрайды.

Р6М5 Болат бетіндегі жабындардың фазалық құрамы бастапқы ұнтақтардың құрамына сәйкес келеді. Бұл ретте дифрактограммаларда жабыны бар үлгілерде төсеніш фазаларының рефлекстері пайда болады. Осылайша, рентгенофазалық талдау тозаңданудан кейін жабында жаңа фазалар түзілмейтінін көрсетті, бұл тозаңдату процесінде төсеудің төмен температурасын растайды. Бұл, өз кезегінде, төсеніштің термиялық өңдеуге ұшырамағанын растайды.

Түйін сөздер: жабын, ауа-плазмалық тозаңдану, құрылым, титан нитриді, плазмотрон, кремний карбиді.

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РАЗРАБОТКА ВОЗДУШНО-ПЛАЗМЕННОЙ ТЕХНОЛОГИИ УПРОЧНЕНИЯ РЕЖУЩИХ ИНСТРУМЕНТОВ ПУТЕМ НАНЕСЕНИЯ ИЗНОСОСТОЙКИХ ПОКРЫТИЙ

Аннотация. Одной из задач дальнейшего развития машиностроения является повышение срока службы металлорежущих инструментов (сверла, метчики, развёртки и др.). Как известно, модифицирование высокоэнергетическим воздействием является эффективным средством повышения срока службы и улучшения физико-механических и эксплуатационных свойств поверхности режущих инструментов.

Повышение эксплуатационных свойств режущего инструмента в значительной мере определяется технологией упрочнения. В связи с этим, в данной работе была поставлена задача разработки технологии упрочнения режущих инструментов путем нанесения износостойких покрытий на рабочей поверхности воздушно-плазменным методом. Авторами данной была разработана и изготовлена установка для воздушно-плазменного напыления (ВПН) покрытий, которая состоит из плазмотрона, системы подачи инертных газов аргона и воздуха, источника питания инверторного типа 500 А с напряжением холостого хода 60 В, системы автономного охлаждения плазмотрона. На основе изучения существующих моделей плазмотрона для ВПН нами была разработана конструкция плазмотрон, который состоит из следующих частей: анод, катод, межэлектродная керамическая вставка, изолирующие керамические узлы, узлы подачи порошка, охлаждающей жидкости, плазмообразующего газа и транспортирующего газа. В разработанной конструкции плазмотроне в качестве рабочего газа используется аргон и воздух, охлаждение корпуса плазматрона осуществляется водным потоком через специальный охлаждающий канал через штуцера подачи охлаждающей жидкости.

С целью оценки работоспособности плазмотрона был произведён термический анализ данной схемы методом конечных элементов SolidWorks. С целью обеспечения более устойчивого возбуждения дуги установка была оснащена системой бесконтактного «возбуждения дуги» на основе осциллятора токов высокой частоты ОССД 500. На разработанной установке воздушно-плазменного напыления был поведён эксперимент по получению карбидных и нитридных покрытий на поверхности быстрорежущих сталей и проведены лабораторные испытания полученных покрытий.

В качестве материала исследования была выбрана быстрорежущая сталь Р6М5. Эксперименты по получению покрытий на основе SiC и TiN проводились в следующем режиме: скорость перемещения 2-30 мм/с, расстояние между плазмотроном и изделием 45-55 мм, диаметр пятна напыления 10-25 мм. Температура нагрева деталей при напылении не превышает 150-200С°. Для улучшения адгезии была проведена предварительная пескоструйная обработка сухим корундом (при давлении воздуха 0,3-0,6 МПа, расстояние от среза сопла струйно-абразивного пистолета до обрабатываемой поверхности составляет 80-100 мм). С целью оценки трибологических характеристик карбидных и нитридных покрытий, полученных методом ВПН, был применен метод исследования износостойкости при трении с помощью устройства, позволяющего измерять силу трения скольжения в переменном движении. Длина пробега составляла 12 м, скорость 2 см/с, нагрузка 5 Н.

Было проведено металлографическое исследование поперечных шлифов образцов с покрытиями. В статье показан коэффициент трения образца при нормальной силе 5 Н и скорости взаимного перемещения 0,94 см/с, значение коэффициента трения находится в пределах от 0,2 до 0,8 μ. Для покрытий TiN характерен более стабильный период приработки: коэффициент трения ~ 0,2 μ. А для подложки из быстрорежущей стали Р6М5 период приработки 7 м составляет уже 0,8 μ. Для покрытий SiC коэффициент трения составил 0,2 μ, а подложки – соответственно 0,3 μ. Фазовый состав покрытий на поверхности стали Р6М5 соответствует составу исходных порошков. При этом на дифрактограммах образцов с покрытием появляется рефлексы подложки. Таким образом, рентгенофазовый анализ показал, что после напыления не образуются новые фазы как на покрытии и так в подложке, что подтверждает низкую температуру нагрева подложки в процессе напыления. Это, в свою очередь, подтверждает отсутствие разупрочнения подложки.

Ключевые слова: покрытие, воздушно-плазменное напыления, структура, нитрид титана, плазмотрон, карбид кремния.

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