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ПРАКТИКА ИСПОЛЬЗОВАНИЯ ЭЛЕКТРОННО-ЛУЧЕВЫХ ТЕХНОЛОГИЙ СВАРКИ, УПРОЧНЕНИЯ И НАПЛАВКИ ЗАЩИТНЫХ ПОКРЫТИЙ В ВАКУУМЕ НА ПРЕДПРИЯТИЯХ ОБОРОННО-ПРОМЫШЛЕННОГО КОМПЛЕКСА

Представлены результаты завершенных исследований и практического применения на предприятиях оборонно-промышленного комплекса изделий со сварными швами и защитными покрытиями, полученными электронно-лучевой сваркой, упрочнением и порошковой электронно-лучевой наплавкой в вакууме.

В результате комплексного анализа коллективом авторов в Проблемной лаборатории процессов сварки и создания защитных покрытий АлтГТУ им. И.И. Ползунова на основе более чем 25-летнего опыта в области электронно-лучевых технологий разработана технология электронно-лучевого упрочнения наиболее технологически сложных поршневых алюминиевых сплавов заэвтектического состава марки АК21М2,5Н2,5. Авторами была разработана и прошла успешное тестирование технология производства составного поршня из высококремнистого алюминиевого сплава АК21М2,5Н2,5, изготовленного из двух частей с последующей их сваркой электронным лучом.

Упрочнение с оплавлением рабочих кромок матриц для горячего деформирования распылителей дизельного топлива позволило на ОАО «Алтайдизель» повысить разгаростойкость поверхности в 2 раза.

Актуальным является практическое использование электронно-лучевой технологии наплавки высоколегированных порошковых сплавов на основе системы Ni–Cr–B–Si для ремонта и восстановления изношенных поверхностей тяжелонагруженных деталей: коленчатых и распределительных валов ДВС, крестовин, шаровых опор, толкателей распределительного валика, ступиц шкивов клиноременных передач, ходовых винтов и др.

Для создания защитных покрытий на уплотнительных поверхностях запорной паровой котельной и трубопроводной арматуры – седел, тарелок и сфер – была предложена технология прямой порошковой электронно-лучевой наплавки в вакууме.

Разработанные технологии могут быть рекомендованы к внедрению на предприятиях Алтайского края, специализирующихся в области двигателестроения при производстве новых или восстановлении и ремонте изношенных деталей и комплектующих для двигателей внутреннего сгорания.

Ключевые слова: качество, надежность, электронный луч, сварка, упрочнение, защитные покрытия,порошковая наплавка в вакууме, комплексное исследование, практическое использование, предприятия ОПК.

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THE PRACTICE OF USING ELECTRON BEAM TECHNOLOGIES OF WELDING, HARDENING AND SURFACING OF PROTECTIVE COATINGS IN VACUUM AT THE DEFENSE INDUSTRY ENTERPRISES

The article presents the results of completed research and practical application of products with welded seams and protective coatings obtained by electron-beam welding, hardening and powder electron-beam surfacing in vacuum at the enterprises of the military-industrial complex.

As a result of the complex analysis by the team of authors in the Problem laboratory of welding processes and creation of protective coatings of I. I. Polzunov AltSTU on the basis of more than 25 years of experience in the field of electron-beam technologies, the technology of electron-beam hardening of the most technologically complex piston aluminum alloys of the hypereutectic composition of the brand AK21M2,5H2,5 has been developed.

The authors developed and successfully tested the technology of production of composite piston from high-silicon aluminum alloy AK21M2,5H2,5, made of two parts with their subsequent electron beam welding. Hardening with the melting of the working edges of the diesel for hot deformation of spray of diesel fuel allowed at JSC "Altaidizel" increasing of heat resistance surface 2 times.

Actual is the practical use of the technology of electron-beam surfacing of high-alloy powder alloys based on the Ni-Cr-B-Si system for repair and restoration of worn surfaces of heavily loaded parts: crankshafts and camshafts of internal combustion engines, crosspieces, ball bearings, camshaft pushers, wheel hubs V-belt drives, propellers, etc.

To create protective coatings on the sealing surfaces of the shut-off steam boiler and pipeline valves – saddles, plates and spheres the technology of direct electron-beam powder deposition in vacuum was proposed.

The developed technologies can be recommended for implementation at the enterprises of the Altai region, specializing in the field of engine building, in the production of new or restoration and repair of worn parts and components for internal combustion engines.

Keywords: quality, reliability, electron beam, welding, hardening, protective coatings, powder cladding process in vacuum, completed research, practical application, the defense industry enterprises.

A significant reserve for increasing the service life of parts and tools is the formation on the surface of these parts and elements of layers and coatings with a high level of required functional properties – wear resistance, hardness, corrosion resistance, etc. Among the existing energy and resource-saving technologies, processes using highly concentrated energy flows, such as plasma jet, light and laser beams, high-energy beams of relativistic electrons and low-energy electron beams are becoming increasingly important. Due to a number of advantages over other concentrated energy flows, electron beam welding and surfacing processes with low energy beams are among the most promising methods of coating.

The practice of operation of internal combustion engines (ice), especially forced diesel engines, shows that the weakest point is the piston area of the annular grooves for compression rings. The formation of the limiting gap between the compression ring and the piston ring groove mainly determines the engine life before the bulkhead, oil and fuel consumption, as well as repair costs. Therefore, the solution to the problem of increasing the life of the piston ring grooves is the main direction for the practical use of the results of scientific research both in Russia and abroad.

The main problems in electron-beam remelting in vacuum of high-silicon piston alloys faced by technology developers are cracking of the remelting zone and a high level of residual porosity of the metal.

To analyze the causes of these problems were studied casting technology and additional processing of aluminum-silicon blanks in specialized enterprises “Piston” (Alma-Ata, Republic of Kazakhstan) and the Sukhoi Company of Novosibirsk aviation plant named after V.P. Chkalov.

As a result of the complex analysis by the team of authors in the Problem laboratory of welding processes and creation of protective coatings of I. I. Polzunov AltSTU on the basis of more than 25 years of experience in the field of electron-beam technologies, the technology of electron-beam hardening of the most technologically complex piston aluminum alloys of the hypereutectic composition of the brand AK21M2,5H2,5 was developed (fig. 1).

The technology of hardening consists in electron-beam remelting of the metal layer in the place of the piston, where the annular groove of the required geometric dimensions is subsequently machined.

The solution of these problems is found by the authors of this article as a result of the analysis of the structure formation of piston blanks in the process of casting and modification, analysis of the thermal state of the piston in the process of remelting the hardening zone and rational choice of the trajectory of high-frequency scanning of the electron beam.

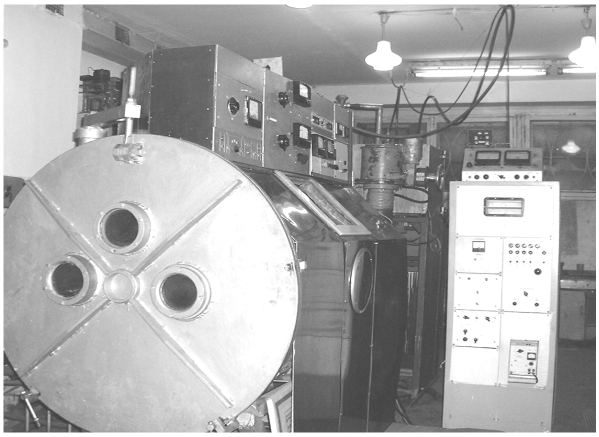


Fig. 1. Laboratory equipment for electron beam vacuum welding and surfacing

For the implementation of forced degassing of the liquid metal bath and a more uniform distribution of alloying elements in it, it was necessary to equip the electron-beam installations with beam control devices (BCD), which allow mixing the melt by scanning electron beam along a given trajectory with a certain amplitude-frequency characteristic. To solve the last problem within 1.5–2 years, a series of specialized electron beam control devices has been developed and manufactured, which have a large memory capacity, a wide range of frequencies and trajectories of the electron beam movement, independent control of the sweep along the coordinate axes, smooth amplitude control and versatility in the use of various types of electron beam guns.

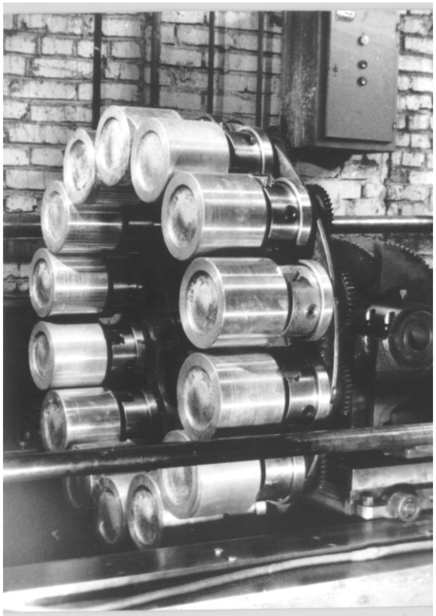
Such characteristics of the BCD allow performing a wide range of technological research and production operations (fig. 2).

Fig. 2. The panel of the developed electronic beam control software device for the process of welding and hardening in vacuum

As a result of complex experimental studies, the optimal technological parameters of the hardening mode are established, allowing to obtain practically defect-free metal in the remelting zone with high wear resistance.

For the practical implementation of the technology of electron beam welding, hardening and powder wear-resistant coating in vacuum in production conditions was designed and put into operation experimental production site at JSC “Barnaultransmash" (fig. 3).

a



b

Fig. 3. Factory unit with electron beam gun with a “cold cathode” (*a*), a control beam device and the 14-position manipulator (*b*) for welding and hardening the pistons

In the process of development of experimental-industrial technology of electron-beam hardening of pistons for diesel engines of JSC “Barnaultransmash” it was found that in this technology there is a significant reserve for increasing the wear resistance of the first annular grooves, namely hardening by alloying, which allows to significantly expand the scope of application of this method of hardening [1-4].

In the case of additional alloying of aluminum alloy in order to obtain even higher wear resistance nichrome or copper wire is proposed to use as an alloying material, the content of which in the deposited metal determines the required mechanical properties, such as hardness and wear resistance.

The appearance of piston blanks with hardened zones under the annular groove is shown in fig. 4. These pistons are equipped with high-speed forced diesel engines.

Fig. 4. Billet pistons from alloy AK21M2,5H2,5 with hardened areas under the groove of the first annular grooves of the compression rings (indicated by arrows)

Conducted production tests of the hardened pistons at work on the uprated diesel engines showed an increase of their service life in 3 times in comparison with diesel engines with unhardened pistons.

One of the problems that arise during the operation of the pistons is to reduce their service life due to the cracking of the piston bottom due to thermal stresses. There are a number of ways to reduce thermal stress, including by changing the design of the pistons, in particular the creation in the area of the first piston groove additional cavity through which the engine oil circulates.

The proposed technology of production of welded piston has certain advantages over similar technologies used to form a cooling cavity in the bottom of the piston, for example, the method of filling salt rods. The use of electron beam welding in vacuum provides a dagger penetration, which prevents the creation of stresses and subsequent deformations.

The authors developed and successfully tested the technology of production of composite piston from high-silicon aluminum alloy AK21M2,5H2,5, made of two parts with their subsequent electron beam welding.

The results of comprehensive testing of the quality of the metal and the entire design of the pistons as a whole showed the practical absence of any defects, which was a fundamental proof of the possibility of using this technology for the production of pistons with a cooling cavity, as shown in fig. 5.

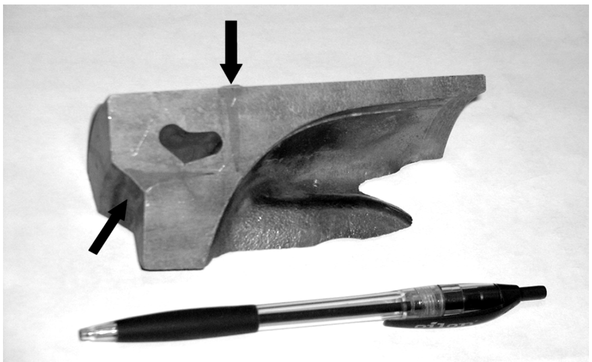


Fig. 5. Templet of the compound welded piston with the cavity of cooling (arrows indicate welds)

Due to the relatively high cost of the equipment, the use of a highly concentrated source of heating – an electron beam in vacuum for welding and the creation of reinforcing and protective coatings is advisable in cases where it leads to qualitatively new results, the properties of welded, hardened and deposited products, as well as when it is impossible to use other methods of surface heating. All this, as practice has shown, lies in the manufacture of products of the military-industrial complex.

To solve similar, non-traditional tasks, the authors performed a set of technological works on electron-beam welding of the cylinder liner body with the landing shoulder for JSC "Barnaultransmash". It has identified savings of expensive alloy steel 38Х2МЮА up to 40 % due to a sharp reduction of the wall thickness of the workpiece and elimination of operation turning (fig. 6).

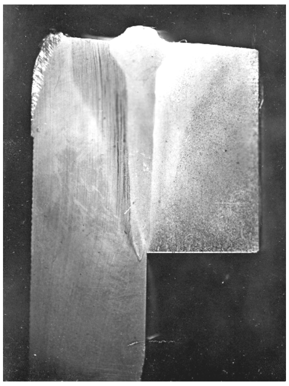


Fig. 6. Electron beam welding in vacuum of the blank of the cylinder liner of the forced diesel with the landing shoulder

In the development of electron-beam technologies, the method of powder surfacing with low-energy electron beams (up to 5 Kev), developed by the team of authors, due to the combination of the advantages of powder materials and vacuum protection of the metal allows to create unique performance hardening layers on the surfaces of various parts of diesels [5-9].

It is very effective by means of hardening and surfacing with an electron beam to create protective layers on the surface of parts with a high level of functional properties (hardness, wear and corrosion resistance) on parts or billets from relatively cheap low-carbon steels. Thanks to the possibility of accurate dosing of energy supply by means of electron beam deposition (EBD), uniform thickness layers are formed with minimal penetration of the substrate, and deformations of non-rigid parts are excluded. The strength of adhesion with the base coating deposited by the method of EBD is on the level of metallic bond. Therefore, in contrast to the sprayed they do not crack and do not peel off as a result of intense multi-cycle contact loads. Multiple cladding after regrinding of welded components is possible. As practical experience shows, the cost of repair of parts is about 30 % of the cost of new ones with significantly higher functional properties of the surface [10-20].

For example, hardening by melting of working edges of matrices for hot deformation of diesel fuel sprayers allowed JSC "Altaidizel" to increase the surface heat resistance 2 times.

Particularly relevant is the practical use of the electron-beam surfacing technology of high-alloy powder alloys based on the Ni-Cr-B-Si system for repair and restoration of worn surfaces of heavily loaded parts: crankshafts and camshafts (fig. 7, 8), cross-pieces, ball bearings, camshaft pushers, wheel hubs V-belt drives, propellers, etc.

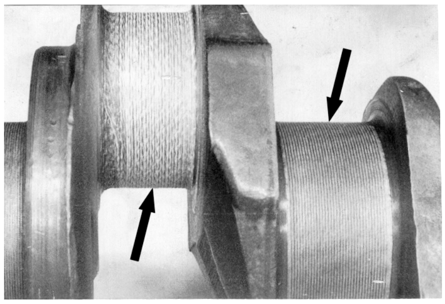


Fig 7. Crankshaft of forced diesel (55Х2Н2МФА steel) with indigenous and connecting rod necks reinforced with center offset of the shaft by the method of electron beam melting in a vacuum

In 2007, the team of authors was awarded the prize of the Altai territory in the field of science and technology for the development and implementation of electron beam welding technology, hardening and surfacing at enterprises of the region.

The practice of operation of pipeline and steam valves of power plants shows that its life largely depends on the quality of sealing surfaces that operate in difficult operating conditions, and currently it is less than the life of other main elements of pipelines and power plants. The valve is designed to control the movement, distribution and flow control of liquids, gases (vapors) by direct impact on them. This is especially true in defense industry enterprises with a continuous schedule of work, in which the quality of production is a determining factor.

Fig. 8. The camshaft of the internal combustion engine after repair using powder electron-beam welding in vacuum

Due to the most difficult operating conditions, only shut-off valves were considered in the work, in particular valves with a nominal diameter of the passage (nominal diameter of the hole in the valve, serving for the passage of the medium DN = 100 mm.

To create protective coatings on the sealing surfaces of the shut-off steam boiler and pipeline valves – seats, plates and spheres the technology of direct electron-beam powder deposition in vacuum (EBP) was proposed. Taking into account the operating conditions of the friction pair and the need to ensure the possibility of subsequent processing, materials for surfacing were chosen chromium-Nickel powder alloy ПГ-10Н-01 on plates and ball surfaces and bronze alloy ПГ-19М-01 on the saddle.

The combination of optimal modes and processes of refining and degassing of the melt, passing during surfacing in vacuum, provided, as shown by the results of metallographic and x-ray analysis, obtaining a dense fine-grained structure of the protective coating (without pores, shells, non-metallic and gas inclusions) with the required level of functional properties. Fig. 9 shows ball valves with working surfaces deposited by an electron beam in a vacuum.

Long-term production tests at the enterprise of JSC "ЭТЭМ" on the basis of the I. I. Polzunov Central Boiler Institute (St. Petersburg) showed an increase in the resistance of the pair of friction finger-saddle 2.5 times compared with steel 08Х18Н10Т.

It seems promising to create welded composite coatings on heavily loaded parts of diesels, when each of the phases – a plastic matrix and solid reinforcing particles of carbides, borides, silicides of refractory elements performs certain functions, creating materials with high physical, mechanical and operational properties.

Fig. 9. Shut-off valves with sealing surfaces hardened by wear-resistant electron-beam surfacing of powder alloys in vacuum

The developed technologies can be recommended for implementation at the enterprises of the region, specializing in the field of engine building in the production of new or restoration and repair of worn parts and components for internal combustion engines.

Good reproducibility of results of hardening and surfacing in the automated mode, possibility of full automation of technological process with computer control, ecological purity, possibility of essential improvement of properties of a surface layer of products in combination with existence of the reliable equipment released in Russia and the neighboring countries, approved within 40-45 years, considerably expands a range of technological operations of processing of details of diesels with use of electron beams in vacuum.

Thus, the solution of the complex problems of the type listed above using unique electron-beam technologies of welding, hardening and surfacing of protective coatings determine their development prospects at the defense enterprises of not only the Altay region but the entire spectrum of the Russian defense machine-building enterprises.

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