DOI: 10.14529/engin210107

SURFACE MODIFICATION OF CAMSHAFTS USING PLASMA MELTING METHOD IN HIGH-FREQUENCY MAGNETIC FIELD

F.M. Shirzadov[1]***,*** *fashirzadov@beu.edu.az,*
R.Y. Dadashov[2]***,*** *mr_dadashov@mail.ru*
[1]*Baku Engineering University, Baku, Republic of Azerbaijan*
[2]*Azerbaijan Technical University, Baku, Republic of Azerbaijan*

Continuous requirements for improving the quality of machines requires new investigation to constantly increase the production performance of parts. In this article, the surface of the cast iron EN-GJV-400 was remelted and modified via TIG (Tungsten-Inert-Gas) welding separately and simultaneously under high frequency magnetic field, as well as the microstructure and hardness of the specimens were compared.

It has been found that with the plasma treating of the surface under high frequency magnetic field the mechanical and tribological properties of the specimens have been improved. The hardness of the specimens from the cast iron EN-GJV-400 was increased after the surface remelting with high frequency and low energetic magnetic field. The microstructures of the modified surfaces through the conventional TIG and high frequency magnetic field were also not same. The reason was that the magnetic energy in the molten material in the latter method caused additional temperature in weld pool as well as the rotation of the it in the direction of the magnetic induction vector. The size of the grains has been increased via the additional heating effect and at the same time the dendrite branches have been cut to the smaller parts. The technology can be applied for the increasing the Hertzian contact pressure, tribological properties of surfaces and for the alloying and shaping processes considering the magnetic force on the molten material.

Keywords: cast iron, magnet, plasma, TİG (Tungsten İnert Gas), ledeburite, modification.

Introduction. Nowadays camshafts which convert rotary motion to reciprocating motion are mostly applied in packaging, printing, sewing machines and especially in valve train of internal combustion engines. Although, these types of mechanical controlling systems have been attempted to be substituted with electromagnetic or electrohydraulic methods, these mechanisms are still effective in modern internal combustion engines [1–6]. Valve train, especially, camshafts which are performing mechanical program function are the central problem in development of the combustion engines, because technical conditions of the engines are determined based on its efficiency and parts of this mechanisms have a great impact on the functional output parameters of the engine [7–10].

In combustion engines, one fifth of the produced energy is not transferred to motion instead, wasted during friction process, whose 30% is originated from valve train, especially, camshaft and cam follower pair [3, 5, 7, 8].

Energy concentrated on the surface of the camshaft by deforming surface roughness leads to gradual damage (wear) to the part, as well as, by deviating from geometrical sizes, issues such as loss of valve control accuracy and degradation of functional output parameter emerge.

Friction, wear, reliability and durability of machine parts depend heavily on the structure of surface layers, which are under stress and its properties, where 90% of failures occur due to worn parts. According to this fact, recently, applying wear resistant claddings on the surface of moving parts by using technological methods are of significance. Regardless of many conducted researches on the topic of wear resistant layers on the surfaces of interacting parts, there still exist many uncertainties about the criteria for application and potential applications in case of certain problems [11, 12].

Analyzed machine parts - camshafts are widely manufactured EN-GJV-400 grade cast iron. Generally, cast iron has a relatively high friction coefficient and less wear resistance, so they are mainly used in machine parts with low contact stress and sliding speed. It should be noted that the widespread cast iron/steel friction pair is located at the boundary permitted for friction and antifriction materials [11]. Therefore, they are not considered to be satisfactory either as friction or antifriction material. Here, the requirement for the machining of cast iron by various methods is raised in order to increase tribological properties [13–15].

One of the technological manufacturing methods of the cast iron is the acquisition of the ledeburite structure on the surface of the cast iron by applying highly concentrated energy source (Tungsten Inert Gas).

However, despite ledeburite structure increases the hardness of the material surface, the loss of graphite that gives it an antifriction property may limit the application of the material during dry friction [11]. In this regard, the article analyzes the cladding and base material microstructures and hardness of the EN-GJV-400 grade cast iron, which are thermally processed by conventional TIG method, along with the combined application of TIG and high-frequency magnetic field (HFM). Here, it was attempted to improve the quality of the cladding as a result of the HFM field positively affecting the geometry of the material and its physical and mechanical properties [16].

1. Materials. By selecting antifriction cladding materials for melting on the surface of camshafts, their chemical composition and some physical properties are given in the tables. Table 1 shows the composition and relative hardness of the cladding wire to be applied by the TIG method in the high frequency magnetic field and Table 2 shows the composition and properties of the alloying foil to be applied to the surface by the TIG method in the high frequency magnetic field.

Table 1

Chemical composition and relative hardness of the cladding wire to be deposited on the surface by the TIG method in the HFM field

TİG-cladding wire	Chemical composition, %					Relative hardness
	C	Si	Mn	Cr	Base element	
UTPADUR600	0,5	3	0,5	9,5	Fe	610HV

Table 2

The composition and properties of the alloying foil that will be applied by the TIG method in the high-frequency magnetic field

Composition and properties of the alloying foil	Chemical composition, %				
	Sn	Cu	Ni	Si	B
CuSn-4: Increase the corrosion resistance and heat conduction, produce fine structure and cause to deposit copper on the surface.	3–5	95–97	–	–	–
Ni alloy foil-Ni78Si8B14: Silicon increases strength, heat resistance, hardness and allows formation of graphite; Nickel facilitates the formation of fine-grained structure and formation of graphite, improves strength and corrosion resistance; Boron carbide improves wear resistance, increase contact temperature and facilitates the formation of graphite.	–	–	78	8	14

2. Objectives. During the experiments, the surface of the samples should be melted applying separately and with the joint application of high frequency current and TIG modifications, using TIG welding method in the high frequency magnetic field.

The specimens are mass-produced EN-GJV-400 cast iron camshaft, and its dimensions and the chemical composition are shown in Fig. 1 and Table 3, respectively.

For plasma cladding in the high-frequency magnetic field, TTH15 heating/melting induction unit with a 15kW power and a TIG 200 AC/DC welder that generates 200-amp current were used. The energy given to material during its processing with high-frequency current is expressed in percentage. The induction current frequency can be increased up to 450 kHz.

In the HFM field, the average frequency of the induction current during processing the base material was set to 200 kHz, the power ranged from 25 to 100% and contraction of the liquefied metal was observed.

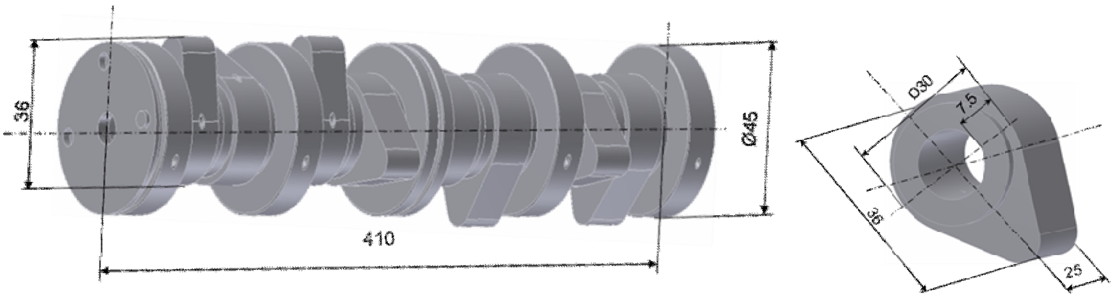


Fig. 1. Dimensions of the analyzed parts

Table 3

Composition of the analyzed base material

Base Material	Chemical composition, %						
	C	Si	Al	Mn	Cr	Cu	Ni
Cam EN-GJV-400	2.7 – 3.8	0.5 – 2.9	< 0.1	0.2 – 0.6	< 0.1	0.6–1.0	0.2 – 0.6

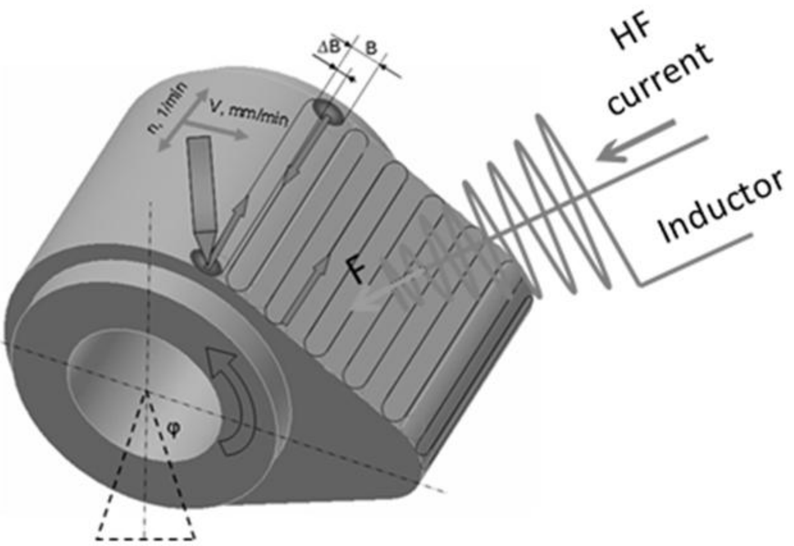
In order to ensure the stability of the molten material, when the TIG was applied jointly with the 140 A and HFC (high-frequency current), the electric current was determined to be 90 A, and the power of the induction device was 25%.

The diameter of the tungsten electrode was 2.4 mm in all experiments, depending on its loading.

Fig. 2 illustrates cladding, surface alloying and modification schemes using TIG method in magnetic environments, and Table 4, Table 5 and Table 6 represents the technological parameters applied in these operations.

Using the EN-GJV-400 cast-iron surface in high frequency magnetic field with the use of TIG cladding, prevents excessive heating of the material in nickel and copper alloying and thus, utilizes only 25% power of the inductive device using only the squeezing effect of the magnetic field to ensure its hardness.

Cam surface alloying in high-frequency magnetic field are conducted according to the sketch given in Fig. 3.



Geometrical parameters:

– Diameter of the spot in burning zone;

– Covering of the weld $\Delta B = f(\varphi)$;

– Electrode angle and distance;

– Geometry of weld bead

Technological parameters:

– Welding speed;

– Frequency of the tungsten electrode;

– Welding current;

– Welding voltage;

– Parameters of magnetic field

Fig. 2. The interaction of the part with the inductor in the modification and alloying of the surface of the cam in the high frequency magnetic field, the motion scheme of weld spot on the surface of cam, geometrical and technological parameters

Table 4

Parameters of surface cladding with UTPADUR600 wire in high frequency magnetic field

Current intensity, A	Height of weld bead, mm	Deposition speed, mm/min	Welding frequency, 1/min	Distance of electrode from surface, mm	Width of weld bead, mm	Wire diameter, mm	Inductor power, %	Inductor frequency, kHs	TİG/Ar shielding gas flow rate, L/min
30–130	<3	50–130	20–40	2–2.5	5–6	ø3.2	25–100	200	8

Table 5

Welding parameters of the surface of cast iron melted by TIG method in high-frequency magnetic field

Current intensity, A	Depth of penetration, mm	Welding speed, mm/min	Welding frequency, 1/min	Electrode distance of from surface, mm	Width of weld bead, mm	Inductor power, %	Inductor frequency, kHs	TİG/Ar shielding gas flow rate, L/min
40–140	<2.5	90–150	40–90	2–2.5	4–6	25–100	200	8

Table 6

Welding parameters of the surface cladding by TIG method in high-frequency magnetic field

Current intensity, A	Depth of penetration, mm	Deposition speed, mm/min	Welding frequency, 1/min	Electrode distance of from surface, mm	Width of weld bead, mm	Inductor power, %	Inductor frequency, kHs	TİG/Ar shielding gas flow rate, L/min
80–145	<3.5	40–70	20–70	2–3.5	5–7	25–100	200	6

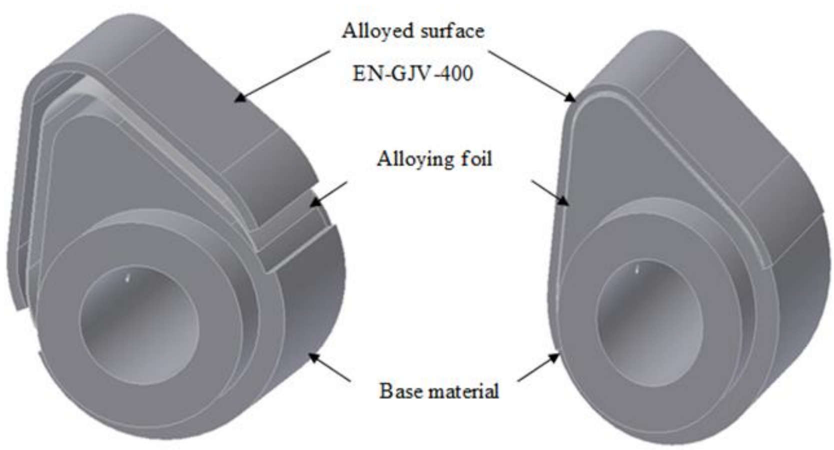


Fig. 3. Schematic description of the surface alloying in high frequency magnetic field

The amount of alloying elements that can be obtained on the surface prior to the alloying of the surface is predetermined theoretically. When the surface of the cam is exposed by TIG surface cladding, the amount of the alloying element is determined by the next expression, depending on the thickness of the foil and the surface to be alloyed.

$$h_R(mm) + h_F(mm) \to 100\% \qquad E_V = \frac{h_F}{h_R + h_F} \cdot 100\% \cdot \left(\frac{E_L\,\%}{100\%}\right),$$

$$h_f(m) \to E_V\,\% \qquad E_V = \frac{E_L \cdot h_F}{h_R - h_F} \tag{1}$$

E_V – required amount of elements on the surface to be alloyed, h_R – thickness of the coated layer, h_F – foil thickness, E_L – amount of element in the alloying foil.

When the amount of the element in the melted zone is known, the thickness of the required foil is determined by the following expression:

$$h_F = \frac{h_R \cdot h_V}{E_L - E_V} \tag{2}$$

3. Results and discussion. Based on the experiment planning, the researchers are inspecting the appearance of cladded parts in the study of the results obtained during the surface treatment. In this regard, let's look at some examples of experiments.

Fig. 4 and Fig. 5 illustrate cams, which surfaces are processed with conventional TIG/high-frequency magnetic field and later polished. As Fig. 4 shows, on the edge of cam there are unacceptable defects caused by material flow. The flow of the material is usually caused by melting of the surface with high energy density in horizontal position. Fig. 5 illustrates the cladded specimen before and after polishing process in the high-frequency magnetic field. Using the Lorentz force created by the high frequency magnetic field on the side wall of the cams, the material flow was prevented in the welding pool and the geometrical defects-sloping edges on the side of the hardened cams were eliminated.

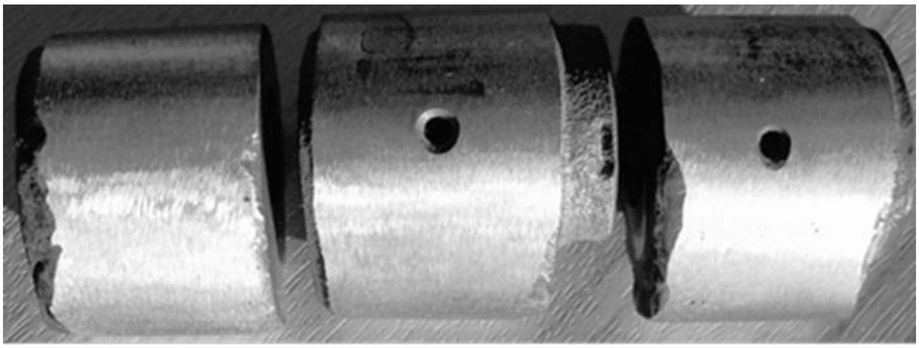


Fig. 4. Flaws of cladded surfaces of cam and its shaft with conventional TIG method

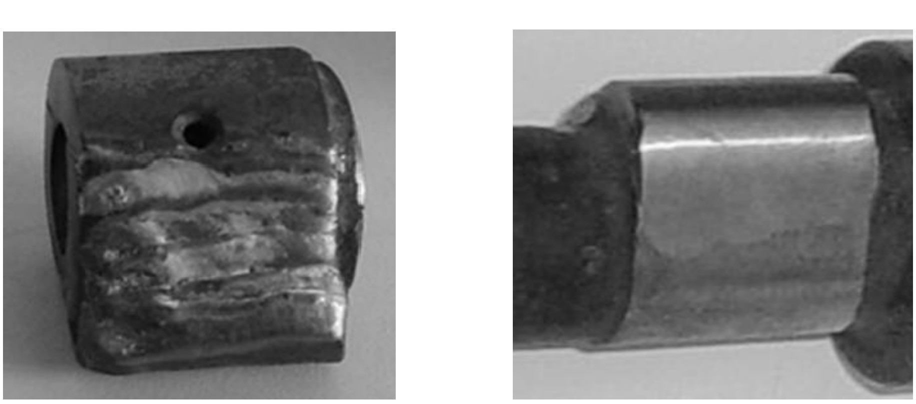


Fig. 5. A general view of surface of cam which remelted and cladded with a high frequency magnetic field TIG-method

Observations shows that fluid content was lifted during the melting process of the cast iron surface by coil-shaped inductors in the high frequency magnetic field. Such melting process can also be applied to prevent flow of the molten material under the effect of gravity force. Increasing the power of the high-frequency current, it has even been possible to pull the material out of the molten liquid from the surface. The reason for this phenomenon is the Lorentz force that affects the surface.

The Lorentz force generated by the induction current will direct the material upward and the Lorentz force in the inductor will squeeze the uprising fluid from the side parts and shape it. Comprehensive analysis of physical and mechanical properties of cladding on surfaces with the application of high frequency magnetic field was determined by its microstructure and hardness. For this purpose, thin sections were prepared from specific concerned parts of the samples and examined using the LEICA DMRM light microscope with the IMATEC image processing software to analyze their structure. However, prior to microscopic analysis, thin sections were etched to improve the visibility.

Fig. 6 shows the base material microstructure of the EN-GJV-400 graded cast iron. The composition consists of perlite, ferrite and free graphite. Since the ferrite and perlite microstructures have relatively low hardness, parts which are made of such materials will have lower allowable Hertzian contact stress on the contact area. From this point of view, the width of the cams from such material is usually wider than the width of the steel cams and this raises an issue in terms of inefficiency in light constructions. Released free graphite from the surface layer during cam's emergency condition reduces the friction coefficient by lubricating the surface and delays part's destruction process.

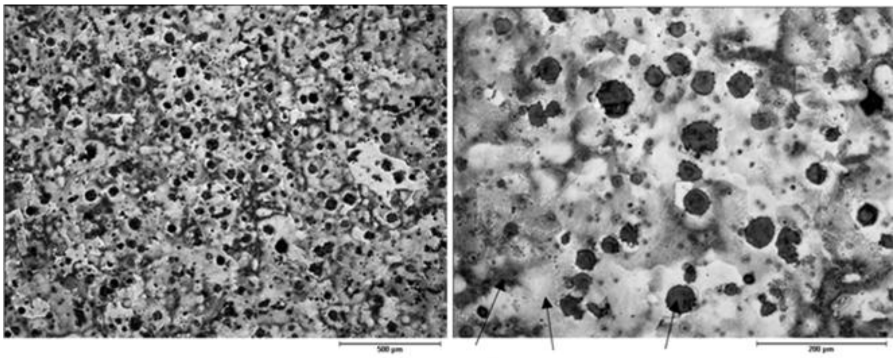


Fig. 6. Microstructure of cast iron EN-GJV-400 grade

Fig. 7 presents the microstructure of cladded surface applying the conventional TIG welding and the TIG welding in high frequency magnetic field using UTP A DUR 600 copper coated wire. It is clear from the microstructures that the Lorentz force that flows from the high-frequency magnetic field to the weld pool and to its magnetic induction has resulted in the separation of the grid shaped chrome carbide existing in the microstructure and as well as the reduction of the amount of pearlite and formation of ferrite.

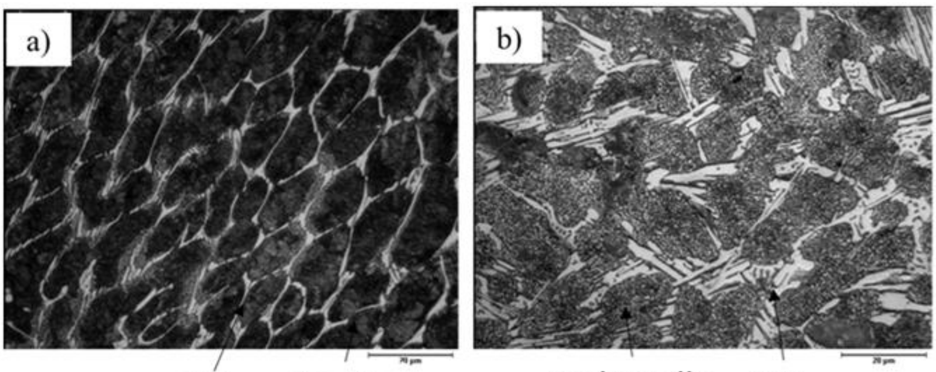


Fig. 7. The microstructure of the surface of the layer UTP A DUR 600 after conventional TIG remelting (a) and TIG remelting in the high frequency magnetic field (b)

In Fig. 8, the microstructure of the TIG remelted cast – iron with and without application of high frequency magnetic field are shown. In both cases the microstructure consists of ledeburite. From the analysis of the microstructure of the both specimens it can be said that the additional temperature and magnetic force in the weld pool caused coarse microstructure and broke the cementite dendrites in structure.

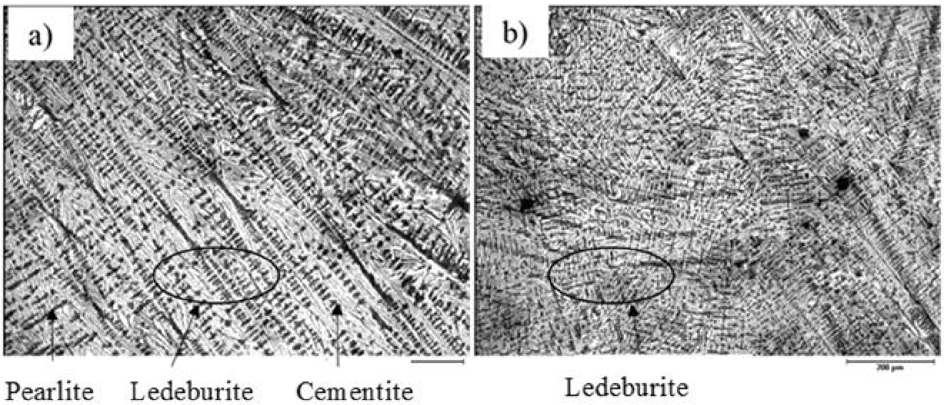


Fig. 8. The microstructure of the layer EN-GJV-400 after conventional TIG remelting (a) and TIG remelting in the high frequency magnetic field (b)

Fig. 9, a and Fig. 9, b are the microstructures of the specimens, which are alloyed with nickel foil via TIG remelting with and without high frequency magnetic field, respectively. There is free graphite in both microstructures and these free graphites improve the antifriction properties of the materials. In addition to that, the needle-like microstructure of the martensite increases the hardness of the material (Fig. 10) and at the same time the Hertz pressure of the surface. The amount of graphite is increased in the case of the alloying in high frequency magnetic field, because of additional induction thermal energy in weld pool.

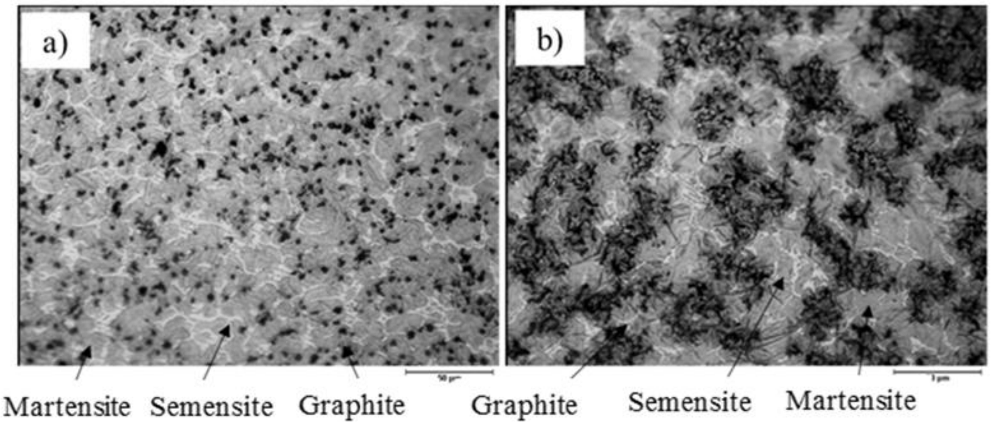


Fig. 9. The microstructure of the nickel alloyed cast – iron via the foil Ni78Si8B14. a – surface alloying via TIG remelting process; b – surface alloying via TIG remelting in high frequency magnetic field

The microstructure of the copper alloyed cast - iron EN-GJV-400 via TİG with and without application of high frequency magnetic field is shown in Fig. 11. In both cases the microstructure consists of hard ledeburite structures in comparison with the untreated EN-GJV-400 base material.

After analyzing the microstructures of the above given specimens, it can be concluded that the microstructures of samples are different via TIG with and without application of high frequency magnetic field. The reasons of this are increasing temperature and rotation of the weld pool in the direction of the magnetic induction vector via the additional magnetic energy. The rotation of the weld pool via magnetic field results in the breaking of the dendrite branches in microstructure.

The hardness of the untreated cast iron EN-GJV-400 was same with the cast iron EN-GJV-400 after remelting in the high frequency magnetic field and cooling in the ambient air. The technology can be applied to the shaping processes of the liquid materials utilizing the motion of the weld pool in the magnetic field.

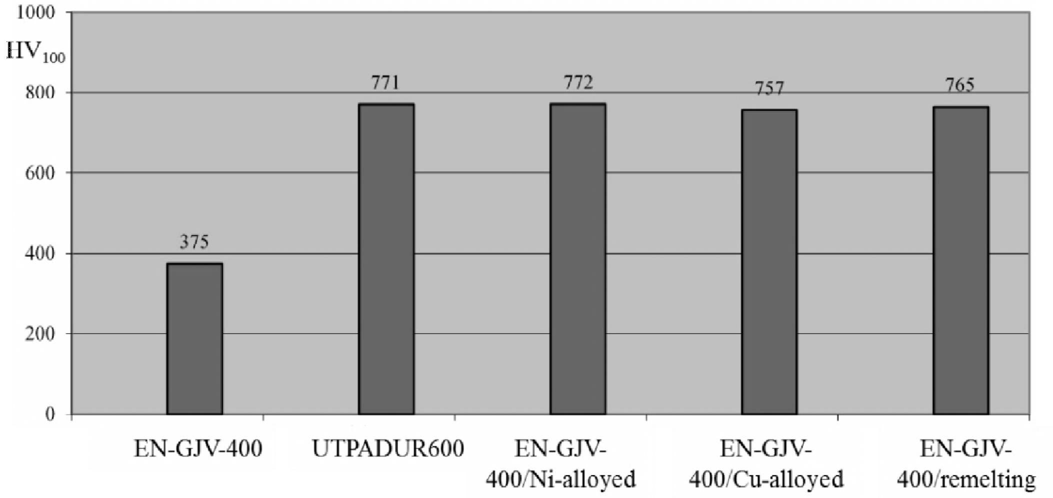


Fig. 10. The hardness diagram of the cladded surface on the cam

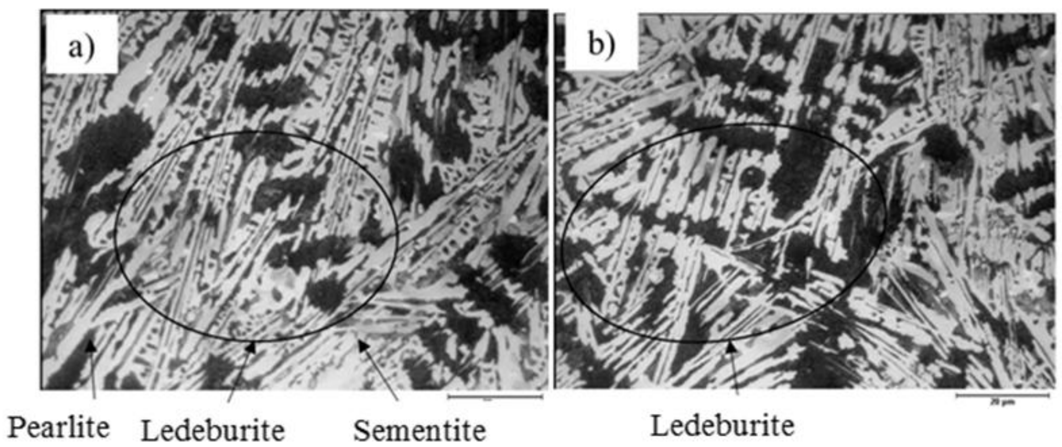


Fig. 11. The microstructure of the copper alloyed cast – iron via TİG (a) and via TİG in high frequency magnetic field (b)

The surface alloyed specimens in the magnetic field have been analyzed via x-ray and the concentration and the chemical composition of the elements in the different depth of the surface layer are given in the Table 7.

Table 7

Distribution of the elements on the surface, modified in the high frequency magnetic field via TİG remelting

Material		Position	Elements, %							
			Sn	Al	Si	Mn	Ni	Cu	Cr	Fe
Base material EN-GJV-400		–	–	0.09	2.41	0.49	0.26	0.67	0.09	Rest
The foils applied to the alloying the surface of the cast-iron	Copper base alloying CuSn-4; 10% Cu alloying	Joining area	**0.06**	0.07	2.15	0.45	0.29	**7.15**	0.05	–
		İn the middle of the modified layer	**0.05**	0.04	2.17	0.43	0.41	**8.57**	0.06	–
		Surface	**0.08**	0.09	2.41	0.49	0.32	**99.1**	0.07	–

Table 7 (end)

Material		Position	Elements, %							
			Sn	Al	Si	Mn	Ni	Cu	Cr	Fe
Base material EN-GJV-400		–	–	0.09	2.41	0.49	0.26	0.67	0.09	Rest
The foils applied to the alloying the surface of the cast-iron	Nickel base alloying Ni78Si8B14; 10% Ni alloying	Joining area	–	0.07	**2.56**	0.40	**8.23**	0.61	0.07	–
		İn the middle of the modified layer	–	0.08	**2.43**	0.44	**9.11**	0.72	0.06	–
		Surface	–	0.10	**2.34**	0.49	**9.32**	0.68	0.09	–

The different physical and mechanical properties of the alloyed materials in comparison with the cast iron and additional rotation of the weld pool via the magnetic force have influenced the hydrodynamics of the weld pool and as a result, the alloyed elements distributed in the surface layer homogeneously. In conclusion, this type of surfaces has high efficiency from the techno-economical point of view and keep their original properties during the exploitation.

The micro-hardness of the modified surfaces in the high frequency magnetic field are given in the Fig. 10, graphically.

As can be seen from the graph in Fig. 10, the hardness of the surface of TIG remelted EN-GJV-400 and copper and aluminum alloyed surfaces have been increased significantly, when compared to the untreated base material EN-GJV-400. The hardness of the TIG remelted surface is higher than the surface remelted in high frequency magnetic field [14–20]. It can be revealed even before the microstructure analysis of the material.

Conclusions. In the article TIG plasma and high frequency magnetic fields were applied separately and together to modify the surface of the specimens and the technology on the base of the surface geometry, microstructure and hardness of the modified surface considering the materials and technological parameters were analyzed.

The hardness of the specimens from the cast iron EN-GJV-400 were the same with the base material after surface remelting and cooling in the ambient air. This technology can be applied to the alloying and shaping processes considering the magnetic force on the molten material, but it cannot be used for increasing the surface hardness.

The microstructures of the modified surfaces through the conventional TIG and high frequency magnetic field are not same. The reason is that magnetic energy in the molten material in the latter method caused additional temperature in weld pool as well as the rotation of the weld pool in the direction of the magnetic induction vector. The size of the grains has been increased via the additional heating effect and at the same time the dendrite branches have been cut to the smaller parts.

The applied technology can be used for manufacturing and repairing the parts, improving the quality of the surface and maintaining it, shaping and alloying in high frequency magnetic field.

Acknowledgenets. The welding processes and the metallographic analyses have been carried out at the Berlin Technical University, in the department of "Joining and surfacing technology". Special Thanks to professor Lutz Dorn for the support during the experiments.

References

1. Ayanoglu H.P. Experimentelle Erfassung des elastohydrodynamischen Kontaktes in Zahnradgetrieben und Nocken/Flachstößel-Paarungen. Diss. RWTH Aachen.
2. Denger D., Mischker K. Die elektrohydraulische Ventilsteuerung. *MTZ*, 2004, vol. 12.

3. Khalilov R.A. *Sistemnyy analiz kulachkovykh mekhanizmov avtomobiley* [System analysis of cam mechanisms of cars]. Baku, 2001. 258 p.

4. Levitsky N.I. *Teoriya mekhanizmov i mashin* [The theory of mechanisms and machines]. Moscow, Publishing Mashinostroyeniye, 1965. 365 p.

5. Rothbart H.A. Cam Design Handbook. McGraw-Hill Professional, 2003. 606 p.

6. Nockenwelle O.. Ein neues elektromechanisches Ventiltriebssystem von Valeo. *MTZ*, 2007, vol. 3, 192 p.

7. Vlotho H.U. Zur Reibung von Nockentrieben mit Flachstößeln. Konstruktionstechnik. Maschinenelemente Nr. 129. VDI-Verlag GmbH Düsseldorf, 1985. 134 p.

8. Holland J., Schmidt A., Clausthal-Zellerfeld. Stößel-Rotation im Nocken-Flachstößel-System. *Technologie Schmierungstechnik* 40 Jahrgang 1/1993, pp. 10–15.

9. Spiegel K. Beiträge zur Elastohydrodynamik bei Nocken-Stößel-Paarungen. Technische Universität Clausthal, 1982. 196 p.

10. Meusburger P. Leichtbau im Motorenbau mit gebauten Nockenwellen. *MTZ,* 2006, vol. 03, pp. 174–179.

11. Shirzadov F. Erhöhung der Verschleißbeständigkeit von Ventiltrieb-Werkstoffpaarungen mittels unterschiedlicher Randschichtmodifikationen. Dissertation, Berlin, 2012. 178 p.

12. Musayev Y.B. Verbesserung der tribologishen Eigenschaften von Stahl/Stahl-Gleitpaarungen für Präzisionsbauteile durch Diffusionsmetallisieren im Vakuum. Dissertation/Universität Erlangen. – Nürnberg, 2001. 180 p.

13. Kuhn M., Hammerl C. Diamantähnliche Kohlenstoff-Schichten für tribologische Anwendungen. *Deutschland: Oberflaeschentechnik*, 2001, Band 61, pp. 121–127.

14. Brand J. Beckmann C., Münnich T., Filfil T. Tribologische Optimierung von Ventiltrieben durch Beschichtungstechnik. *Tribologie, Schmierungstechnik*, 2001, vol 48, no. 1, pp. 22–26.

15. Heck K. Einfluss der Prozessführung beim Umschmelzhärten auf die Randschichteigenschaften von Nockenwellen aus ledeburitischem Gusseisen: / Dissertation für Dr.-Ing.) München, 1983. 173 p.

16. Shirzadov F.M., Sadikhov A.I., Gasimova L.A. [Surface Surfacing Under the Influence of a Magnetic Field]. *Mechanical Engineering Bulletin*, 2015, vol. 3, pp. 50–52. (in Russ.)

17. Willermet P.A. The composition of lubricant – derived surface layers formed in a lubricated cam/tappet contact II. Effects of adding overbased detergent and dispersant to a simple ZDTP solution. *Tribology International*, 1995, vol. 28 (3), pp. 163−165.

18. Stipek T. Neue Gesichtspunkte bei der Auslegung von Nocken fuer Dieseleinspritzpumpen. *MTZ*, 1980, vol. 41 (1), pp. 13–18.

19. Wetzig A., Lepski D., Brenner B. Induction assisted laser remelting of gray cast iron with different chromium contents. *Lasers in Engineering*, 2000, Band 10, pp. 19–35.

20. Holland, J. Degenhardt Ch. Untersuchung des Temperaturverhaltenes von Nockentrieben. *MTZ*, 1988, vol. 49 (10), pp. 391–395.

Received 12 March 2021

УДК 621.43.038.6:669.268 **DOI: 10.14529/engin210107**

МОДИФИКАЦИЯ ПОВЕРХНОСТИ РАСПРЕДЕЛИТЕЛЬНОГО ВАЛА МЕТОДОМ ПЛАЗМЕННОГО ПЛАВЛЕНИЯ В ВЫСОКОЧАСТОТНОМ МАГНИТНОМ ПОЛЕ

Ф.М. Ширзадов[1], Р.Е. Дадашов[2]

[1]Бакинский инженерный университет г. Баку, Республика Азербайджан
[2]Азербайджанский технический университет, г. Баку, Республика Азербайджан

Постоянное повышение требований к качеству машин требует новых исследований и разработок в области проектирования новых технологических процессов и прогрессивных методов обработки для непрерывного повышения производительности деталей. В качестве одного из подобных вопросов в этой статье рассматривается проблема напыления различных износостойких материалов на поверхность распределительного вала с целью повышения его коррозионной и износостойкости. Поверхность чугуна марки EN-GJV-400 была переплавлена и модифицирована сваркой ВИГ (вольфрамовый инертный газ) отдельно и одновременно в высокочастотном магнитном поле, а также сравнивается микроструктура и твёрдость образцов. При этом установлено, что при плазменной обработке поверхности в высокочастотном магнитном поле механические и трибологические свойства испытуемых образцов улучшаются. Твёрдость образцов из чугуна марки EN-GJV-400 была существенно увеличена после поверхностного переплава высокочастотным и низкоэнергетическим магнитным полем. Микроструктура поверхностей, модифицированных с помощью обычного ВИГ и высокочастотного магнитного поля, также не была одинаковой. Причина этого заключалась в том, что магнитная энергия в расплавленном материале при последнем методе обработки вызывала дополнительную температуру в сварочной ванне, а также его вращение в направлении вектора магнитной индукции. Размер зёрен был увеличен за счёт дополнительного нагрева, и в то же время ветви дендритов были разрезаны на более мелкие части. Данная технология может применяться для увеличения контактного давления Герца, трибологических свойств поверхностей, в также для процессов легирования и формования с учётом магнитной силы, действующей на расплавленный материал.

Ключевые слова: чугун, магнит, плазма, TİG (аргонодуговая сварка), ледебурит, модификация.

Литература

1. *Ayanoglu, H.P. Experimentelle Erfassung des elastohydrodynamischen Kontaktes in Zahnradgetrieben und Nocken/Flachstößel-Paarungen: Diss. / H.P. Ayanoglu. – RWTH Aachen.*
2. *Denger, D. Die elektrohydraulische Ventilsteuerung / D. Denger, K. Mischker // MTZ. – 2004. – Vol. 12.*
3. *Халилов, Р.А. Системный анализ кулачковых механизмов автомобилей / Р.А. Халилов. – Баку, 2001. – 258 с.*
4. *Левицкий, Н.И. Теория механизмов и машин / Н.И. Левицкий. – М.: Изд-во Машиностроение, 1965. – 365 с.*
5. *Rothbart, H.A. Cam Design Handbook / H.A. Rothbart. – McGraw-Hill Professional, 2003 – 606 p.*
6. *Nockenwelle, O. Ein neues elektromechanisches Ventiltriebssystem von Valeo / O. Nockenwelle. – Aachen, 1993. – 192 p.*
7. *Vlotho, H.U. Zur Reibung von Nockentrieben mit Flachstößeln / H.U. Vlotho // Konstruktionstechnik .Ser. "Maschinenelemente". – 1985. – No. 129. – 134 p.*
8. *Holland, J. Stößel-Rotation im Nocken-Flachstößel-System / J. Holland, A. Schmidt // Technologie Schmierungstechnik. – 1993. – Vol. 1. – P. 10–15.*
9. *Spiegel, K. Beiträge zur Elastohydrodynamik bei Nocken-Stößel-Paarungen / K. Spiegel. – Technische Universität Clausthal, 1982. – 196 p.*

10. Meusburger, P. Leichtbau im Motorenbau mit gebauten Nockenwellen / P. Meusburger // MTZ. – 2006. – Vol. 03. – P. 174–179.

11. Shirzadov, F. Erhöhung der Verschleißbeständigkeit von Ventiltrieb-Werkstoffpaarungen mittels unterschiedlicher Randschichtmodifikationen: Dissertation / F. Shirzadov. – Berlin, 2012. – 178 p.

12. Musayev, Y.B. Verbesserung der tribologishen Eigenschaften von Stahl/Stahl- Gleitpaarungen für Präzisionsbauteile durch Diffusionsmetallisieren im Vakuum. Dissertation / Y.B. Musayev. – Nürnberg: Universität Erlangen, 2001. – 180 p.

13. Kuhn, M. Diamantähnliche Kohlenstoff-Schichten für tribologische Anwendungen / M. Kuhn, C. Hammerl // Deutschland: Oberflaeschentechnik. – 2001. – Band 61. – P. 121–127.

14. Tribologische Optimierung von Ventiltrieben durch Beschichtungstechnik / J. Brand, C. Beckmann, T. Münnich, T. Filfil // Tribologie, Schmierungstechnik. – 2001. – Vol. 48, No. 1. – P. 22–26.

15. Heck, K. Einfluss der Prozessführung beim Umschmelzhärten auf die Randschichteigenschaften von Nockenwellen aus ledeburitischem Gusseisen: Diss. für Dr.-Ing. / K. Heck. – München, 1983. – 173 p.

16. Ширзадов, Ф.М. Наплавка поверхности под действием магнитного поля / Ф.М. Ширзадов, А.И. Садыхов, Л.А. Гасимова // Вестник машиностроения. – 2015. – Т. 3. – С. 50–52.

17. Willermet, P.A. The composition of lubricant – derived surface layers formed in a lubricated cam/tappet contact II. Effects of adding overbased detergent and dispersant to a simple ZDTP solution / P.A. Willermet // Tribology International. – 1995. – Vol. 28 (3). – P. 163–165.

18. Stipek, T. Neue Gesichtspunkte bei der Auslegung von Nocken fuer Dieseleinspritzpumpen / T. Stipek // MTZ. – 1980. – Vol. 41 (1) – P. 13–18.

19. Wetzig, A. Induction assisted laser remelting of gray cast iron with different chromium contents / A. Wetzig, D. Lepski, B. Brenner // Lasers in Engineering. – 2000. – Band 10. – P. 19–35.

20. Holland, J. Untersuchung des Temperaturverhaltenes von Nockentrieben / J. Holland, Ch. Degenhardt // MTZ. – 1988. – Vol. 49 (10). – P. 391–395.

Ширзадов Фархад Махаммад оглу, доктор философии по технике, доцент, заведующий кафедрой «Механическая инженерия», Бакинский инженерный университет, г. Баку, Республика Азербайджан, fashirzadov@beu.edu.az.

Дадашов Рамиль Енгибар оглы, ассистент кафедры «Технология машиностроения», Азербайджанский технический университет, г. Баку, Республика Азербайджан, mr_dadashov @mail.ru.

Поступила в редакцию 12 марта 2021 г.

ОБРАЗЕЦ ЦИТИРОВАНИЯ

Shirzadov, F.M. Surface modification of camshafts using plasma melting method in high-frequency magnetic field / F.M. Shirzadov, R.Y. Dadashov // Вестник ЮУрГУ. Серия «Машиностроение». – 2021. – Т. 21, № 1. – С. 69–80. DOI: 10.14529/engin210107

FOR CITATION

Shirzadov F.M., Dadashov R.Y. Surface Modification of Camshafts Using Plasma Melting Method in High-Frequency Magnetic Field. *Bulletin of the South Ural State University. Ser. Mechanical Engineering Industry*, 2020, vol. 21, no. 1, pp. 69–80. DOI: 10.14529/engin210107