GAS DETONATION TECHNOLOGY OF SURFACE HARDENING

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ABSTRACT

A new method of surface hardening - gas detonation technology - is a subject of this paper. A main idea and a principle of operation of device in which a controlled explosion of gas mixture propane-butane with oxygen is used to impart proper speed to powdered materials used for hardening. It became possible to control the speed of particles depending on the chosen technological parameters. The effect of the sprayed particles on structure of surface layer of material and also on change of residual stresses has been discussed. Possibilities of practical application of this method in industry have been presented.

KEY WORDS

Gas-detonation technology, surface hardening, particles speed, surface layer.

INTRODUCTION

There are many kinds of plastic cold treatment (e.g. shot peening) for surface hardening. Various kinds of devices are used to do it - rotor, pneumatic and centrifugal ones - depending on the media which are used. The pneumatic devices make use, first of all, of compressed air as a carrier of hardening materials. In last years a new technology of surface hardening has been involved, which allow to use other gases in this process. This is gas detonation spraying /D-gun/ method. This technology is based on technical gases combustion with their maximal speed – detonation. The most typical gases used for this process are: propane-butane, acetylene and some time even hydrogen. These gases in precise, stoichiometrical ratio with oxygen give explosive mixture. A first device in which detonation was used to impart velocity to the particles, was elaborated in 1955 by Linde, a member company of Union Carbide. Then, at early 60-ies the similar devices were invented in former Soviet Union: Institute of Hydrodynamics, Academy of Science in Nowosybirsk, Institute of Welding. A.S. in Kiev, Institute of Metallurgy in Czelabinsk and Industrial Plants in Bernaul. In Poland this technology was introduced at early 90-ies. Till now utilisation of gas detonation spraying was limited – the method was used only for very special processes. The devices manufactured in the United States were not sold abroad and those manufactured in Soviet Union were sold to some countries in South - East Asia, Cuba, Finland. Totally there are some scores of them, mainly in the United States, Russia and Ukraine.

Device for gas detonation surface hardening

The main idea how to construct a device for gas detonation surface hardening came fom the effects which happen in one-side closed tube during detonation (Fig. 1).

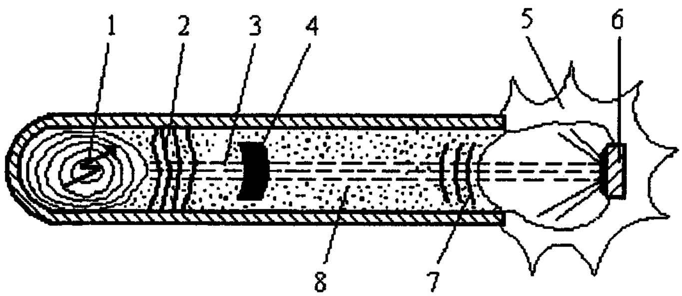

Fig. 1 Scheme of creation of particle flux by gases detonation: 1 – thermal wave (place of combustion initiation); 2 - shock wave; 3 – gas explosive mixture containing particles of powdered material; 4 – detonation wave; 5 – flame at the tube mouth; 6- a workpiece; 7 – backward waves; 8 - unburned explosive mixture.

The principle of operation is very simple. When the tube is filled in with the proper gas mixture in result of initiation (electrical ignition), the process of gas combustion changes to detonation. The powdered material put between detonation wave and tube mouth is substantially accelerated. The powders going out from the tube strike the exposed surface causing changes in properties of its surface layer.

The velocity of detonation wave propagation differs and depends on the used mixture. For mixture of acetylene and oxygen it is about 2450 m/sec., for propane – butane with oxygen 2257 m/sec. These high speeds cause that the velocity of the particles is also very high and reaches 600 – 1200 m/sec i.e. two- threefold of sound speed. However, to obtain the above parameters it is necessary to construct a proper detonating device which will allow to control parameters of two-phase stream (gases and powder) and particularly: velocity of particles, their temperature and density of the stream along its axis [1,2].

Nowadays there are two basic types of devices: old type – with valves and of new generation – valveless one. The main difference between them is that in old-type devices all gases and powder materials are supplied to the instrument through the system of valves. During procedure of dozing all valves are opened to deliver all media, then they close automatically and the initiation of the explosion begins. When the powder materials leave the tube the valves open again and doze powder and gases. The time of opening and the pressure of applied oxygen and acetylene (or propane-butane) decide about quantity and stoichiometrical composition of the supplied gases. In valveless devices the quantity of gases and their composition are regulated by configuration of special nozzles.

At present there are several constructions of devices which differ with place of gas dozing, methods of feeding with powder, diameter of tube and frequency of cycles. Working in cycles is characteristic for all types of devices, new and old ones. Each cycle has the following steps: 1/ filling with gases - oxygen and propane-butane; 2/ feeding with powder; 3/ ignition and combustion of gas explosive mixture; 4/ creation of stream of powder grains and their acceleration towards the front of combustion (detonation wave); 5/ outflow of products of detonation containing the grains of powder; 6/ effects of detonation products and grains of powder on the workpiece. Till now the frequency of cycles, depending on construction and usage of devices varies from 1Hz to 12Hzs. Actual researches aim to increase the frequency to 100 Hzs or more. The diameter of the tube is a very important parameter. It decides, among others, about efficiency of the device and possibility of its application. The devices used now have tubes of diameter 10 – 25 mm. It is obvious that the diameter of tube is not the same as a mark which appear on the workpiece. When the tube with diameter 25 mm is used, the mark on the workpiece has diameter about 32 mm after one cycle [3].

The surface of the treated workpiece is exposed, by means of a proper manipulator, to the spray of powder grains. The surfaces which should not be worked, ought to be covered. The scheme of a valveless gun for gas detonation spraying technology of surface hardening is shown in Fig. 2.

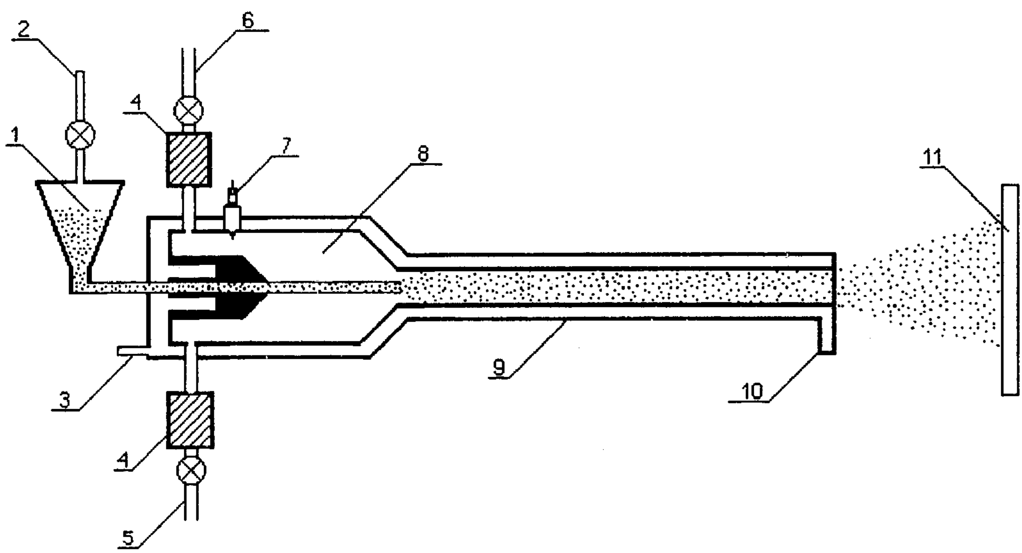

Fig. 2 Schematic view of gas detonation spraying gun for surface hardening:
1/ powder feeder, 2/ nitrogen feed, 3/ cold water feed, 4/ fuse, 5/propane-butane or acetylene feed, 6/ oxygen feed, 7/ ignition system, 8/ detonation chamber, 9/ tube, 10/ draining of water, 11/ workpiece.

A significant feature of gas detonation method is the possibility to impart the controlled and simultaneously so high velocity to the powder particles which is impossible with other methods

VELOCITY OF PARTICLE FLUX

The velocity of particles, their kinetic energy decide about the obtained properties of the surface layer of the workpiece. The velocity can be controlled by changes of ratio of gas mixture, kinds and volume of delivered gases. The length of the tube and distance between tube mouth and the workpiece influence also the final velocity. There are some methods to measure the velocity of the exhausted grains of powder. The results for powder of 22 – 65 μm grain size in function of the tube length, examined in optical method using camera FEN, are presented in Fig. 3.

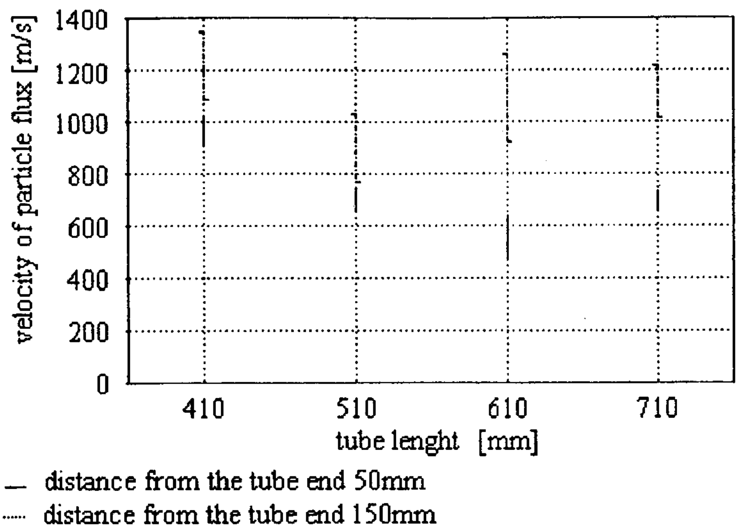

Fig. 3 Effect of tube length and distance between tube mouth and workpiece on the velocity of powder particle flux (granulation 22 - 65 μm) [4].

The above data show that the kinetic energy of the particles can be significantly changed and controlled. The measurements done 50 mm from the tube mouth show the highest velocity even 1300 m/sec. while the lowest values were below 800 m/sec. These values change in function of the distance. For 150 mm from the tube mouth for the same grain size the velocity varied from 500 m/sec. to 1000 m/sec. For a given granulation the change of tube length can give change of velocity even to 100 %. The powder granulation significantly influences the velocity: the greater granulation – the smaller velocity because of particles' weight. For smaller grains the velocity values increase. For instance with grain size 90 – 125 μm the velocity up to 1000 m/sec can be reached. It is very important to use grains of similar size for a given technological process: the precise technological parameters will allow to impart similar velocity to all particles. These as well as the fact that the grains are not fed in closed cycle (the reversing particles do not come back to the device after each explosion) the whole surface of the workpiece is treated with the same force.

PROPERTIES OF SURFACE LAYER.

Applying of gas detonation spraying technology for surface hardening causes the essential changes in structure and properties of surface layer of the workpiece. In result of the procedure there appears a deformation similar to that which appears after peening. Fig 4 illustrates a typical structure obtained in result of gas detonation spraying. The following parameters of the process were selected: explosive mixture – oxygen and propane-butane in ratio 1:4,5; powder was fed by nitrogen under pressure 0,1Mpa, the distance between tube mouth and the specimen was 200 mm, frequency of cycles – 5Hzs, velocity of media– about 700 m/sec. Steel

Structural evaluations of the deposited coating were made by using JEOL scanning microscope JXA-50A

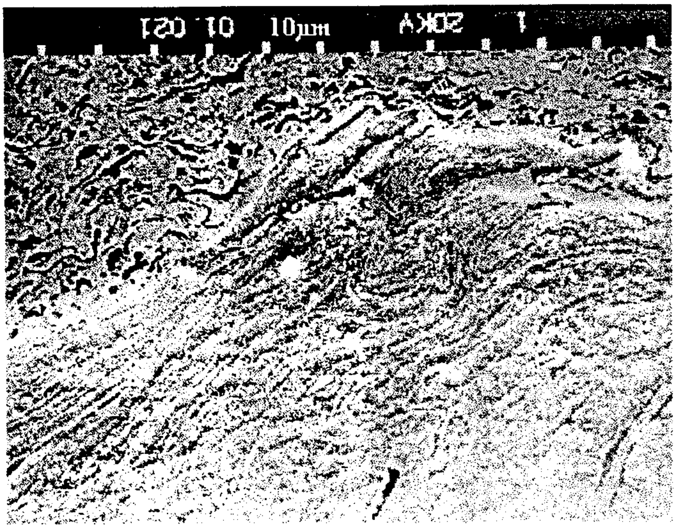

Fig. 4. Structure of surface layer of steel 45 specimen after gas detonation spraying.

Figure 4 shows the hardened surface layer in result of using 90 – 120 μm grain size corundum. In result of interaction of medium, a strong deformation about 0,2 mm deep has appeared on the surface. It is very significant for the obtained layer that there have been observed strongly deformed grains of the worked material. Most of them were laid in parallel to the surface. The strong deformation caused also "swirls" of structure. The estimated results show that plastic strain in deformed layer comes even to 1000 %. It means that energy delivered by the grains of powder enables 10 times elongation of particular grains without appearing of discontinuity of tested material. The observation proved that separate grains of powder in result of kinetic energy penetrate the substrate so deeply that they can be removed only mechanically. The tests showed that microhardness of the near – surface region of substrate increased to 500 – 700HV0,02.

Strong surface deformation in result of detonation coating creates residual stresses. Fig. 5 shows a typical distribution of residual stresses in result of gas detonation coating according to the above mentioned parameters.

The presented distribution of residual stresses prove that detonation spraying created compressive residual stresses of max. value 700Mpa. The highest values of these stresses appeared in layer of about 0,2 mm. This depth corresponds with the thickness of layer strongly deformed in result of detonation. Abrupt fall of value of residual stresses below this thickness is connected with transition of hardened structure to the native material of the specimen.

APPLICATION

There are some aspects of utilisation of gas detonation spraying technology. This technology can be used for surface treatment for two main purposes: 1/ as a pre-treatment of substrate before spraying of layers; 2/ as a treatment generating properties of surface layer.

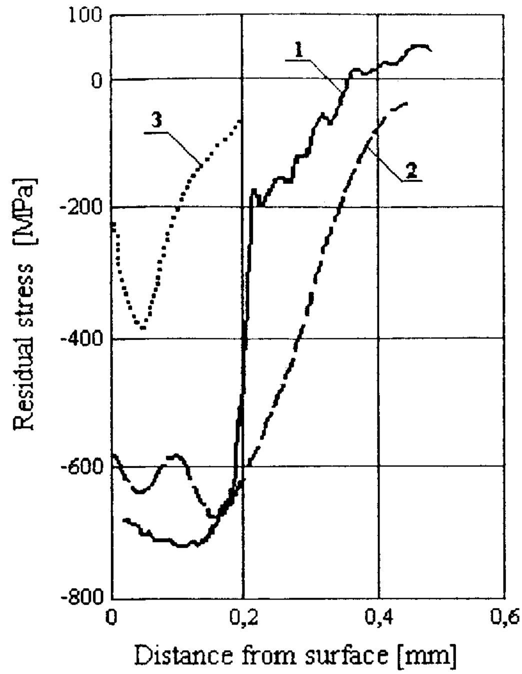

Fig. 5. Distribution of residual stresses in steel 45 after: 1/ detonation shot peening, 2/ pneumatic shot peening [5], 3/ shot peening on centrifugal machine /v=48m/s, cut wire φ=0,5mm, hardness HV 412/ [6].

The main purposes of pre-treatment are: 1/ precise cleaning of the surface, 2/ activation of the substrate, 3/ expansion of the surface. Fort pre-treatment various powders of different granulation are used: glass shot, alundum, alumina of precisely defined fraction e.g. 22-45 μm, 45-63μm, 63-90μm. The chosen fraction and parameters of the process have to be strictly connected and matched to the cleaned material. Absolutely different parameters and powders are used for aluminium alloy than to 60HRC steel. They have to be matched experimentally, otherwise the surface can be damaged in result of high energy of the sprayed powder. Gas detonation pre-treatment is used for large surfaces. The same device can be first used for cleaning and then, after change of powder, for coating. This method allows to work in stages – some parts can be cleaned and coated and after some time the job can be continued without any influence on the properties of the object.

The gas detonation spraying technology, thanks to the high velocity of particles, is mainly used for coating with various kinds of powders. The sprayed coating are generated to:
1/ improve properties of new elements. It allows to use common steel instead of high-alloy steel.
2/ regenerate parts of machines.

At present several hundreds kinds of powders are used depending on the aim. Some of them are used most often e.g. carbide powders (wolfram carbide, chromium carbide, titanium carbide), oxide powders (aluminium oxide, chromium oxide, titanium dioxide), alloy powders (based on nickel alloys, cobalt alloys, ferrous alloys cupro alloys and others), metal powders. The special powders (mixtures or alloys) e.g. WC + Co, Al_2O_3 + TiO_2 and others are, however, used more often. The possibility of creating new mixtures of powders in optional composition and proportion allows to use gas detonation method for various purposes. The main purposes of coatings sprayed on the parts of machines are: 1/ increase of wear resistance in normal and

higher temperature (oxides, carbides and their mixtures with metals are used), 2/ increase of high-temperature corrosion resistance and erosion (mainly oxides, carbides and their mixtures with carbon, nitrogen, wolfram, chromium, vanadium aluminium are used), 3/ increase of thermal and mechanical stroke resistance, 4/ increase of properties of self-lubricating layers (sulfides and selenides of molybdenum, tantalum, niobium are mostly used), increase of cavitation resistance, 6/ increase of frontal and circumferential tightness .
The coatings can be sprayed on all types of steel (up to hardness 64HRC), non-ferrous metals, cast iron and even glass.

The coatings sprayed by gas detonation are till now used on thousands of various types and dimensions of parts, most often in industry (aircraft, armaments, machine-building, paper, food, and others). The sprayed coating improve mechanical properties of machine parts several times.

The gas detonation technology is not wildly used for final treatment generating properties of surface layer. There are not many devices for this purpose all over the world and the elementary cost of such treatment on one square decimetre of surface is very high. The majority of companies which use this method do not publish information about works which they do.

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