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INFLUENCE OF LUBRICATING-COOLING TECHNOLOGICAL MEDIA ON METAL DESTRUCTION DURING CUTTING

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The influence of lubricating and cooling technological means on the destruction of metal during cutting is shown. It has been established that the most effective additives to lubricating and cooling technological means (LCTM) are aliphatic limiting polymers, namely polyethylene (PE) and polyvinyl chloride (PVC). Within the framework of ideas about the chemical activation of media, as well as the accumulated experimental materials of our own research, studies have been conducted on the qualitative description of sophisticated models related to the actual microstructure of the material and quantitative measurements of metal-hydrogen systems. Various aspects of the problem of mechanical energy and hydrogen influence on the restructuring of crystal lattices and the disruption of the interatomic bonding forces arising in ultramicroscopic regions are considered. An important problem is the model of interaction of hydrogen with the metal directly in the region of rearrangement and rupture of bonding forces between atoms. This model corresponds most adequately to the costs of opening a new surface, i.e. the final manifestation of the LCTV influence on the cutting process. The article describes the processes and phenomena that take place below the boundary of the highly deformable metal (chips) and the rest of the metal mass of the workpiece, as well as the peculiarities of the processes of transporting hydrogen from the plasma to the metal fracture zone. It has been established that in the microvolume of the material, the thermal energy produced in connection with the contact interactions of electrically active hydrogen particles with an electrically active real metal structure increases the frequency of thermal vibrations of material atoms and the probability of their rupture. Acting in conjunction with the mechanical energy, they facilitate the processes of deformation and destruction, and reduce the energy costs of cutting metal in various hydrocarbon LCTM. It is noted that the presence of hydrogen both in the chips and in the surface being treated was registered during the cutting of metal in any hydrogen-containing medium, even in water. However, the concentration of hydrogen in the metal workpiece, when the latter is processed in the medium with the addition of a polymer, is approximately two orders of magnitude higher than in the low molecular weight one. It is this fact that makes a significant advantage of LCTM with polymer additives.

Keywords: hydrogen, metal, processing, atom, proton, lubricating-cooling technological media (LCTM).

Introduction

Studies on the mechanism of the LCTM influence on the processes of destruction of metals during their machining by cutting made it possible to establish that the deformation and destruction under such conditions are facilitated due to the interaction of positively charged hydrogen particles with the electrically active real structure of the material, with the structure being formed due to mechanical action [1, 2]. According to these concepts, the formation of ionized hydrogen occurs under the conditions of opening a new surface in the metal fracture zone due to the activation of both low and high molecular substances that are part of LCTM. It is noted that the activation processes take place under the influence of numerous physicochemical phenomena that have a quantum nature, and are a constant companion of acts of the restructuring and breaking of material interatomic bonds. It is also important to note that the presence of a high-molecular compound inside the LCTM repeatedly increases both the rate of activation processes and the yield of the final product (hydrogen) [1, 2].

In general, it should be stated that, to date, although some work has been done on the problem under consideration, further research on the qualitative description of complicated models related to the actual microstructure of the material, and then the quantitative measurements of these metal-hydrogen systems, is still very important.

To qualitatively unite the macro- and micro presentations of various processes and phenomena occurring in ultramicroscopic regions, where the crystal lattice is rearranged and the interatomic bonding forces

are broken due to the cumulative influence of mechanical energy and hydrogen, we consider only some basic aspects of this problem.

On the one hand, these are the peculiarities of the behavior of a high-molecular compound (polymer), which is part of LCTM, and its low-molecular model in the chemical processes of their pyrolysis, which affects not only the concentration rate of the radically active gas mixture, but also the final result, namely the effectiveness of such LCTM.

Overwhelmingly, all modern LCTM, without which it is impossible to carry out the process of obtaining parts with a given accuracy and surface quality, are hydrocarbons whose molecules consist of atoms of only two elements, namely carbon and hydrogen. Other classes of organic compounds, commonly used for the production of LCTM, also consist of hydrocarbons, in whose molecules one or several hydrogen atoms are replaced by various other atomic groups. In contrast to low-molecular substances, polymers that are introduced into their composition as additives, are also organic compounds, but their macromolecular chains consist of molecules of their low-molecular analogs that are united together in a macrochain, and the molecular weight of the polymers can reach many millions.

It has been established [3] that the most effective additives to LCTM are aliphatic terminal polymers, namely polyethylene (PE) and polyvinyl chloride (PVC). In addition, such polymers make it possible to trace the significant differences in the reactivity of low and high molecular weight compounds of similar chemical nature, which are part of LCTM, but with a gradually increasing molecular weight, for example, from low molecular weight ethylene (CH_2) to high molecular weight PE whose molecular weight can exceed 100×10^3 , and its composition corresponds to one general formula with a constant homologous difference of CH_2 .

The methodical attractiveness of these substances also lies in the fact that PE, unlike, for example, heptane, with its low thermal stability, easily decomposes, forming active forms of hydrogen and carbon [3]. The high concentration of hydrogen in the rupture zone has a strong effect on the rearrangement and rupture of interatomic bonds, which causes, compared with heptane, a drastic decrease in strength.

On the other hand, in the metal-hydrogen system under consideration, of interest is the kinetics of the proton penetration deep into the metal, which is carried out at a rate significantly higher than that of body deformation during the cutting process. The determination of the nature of this phenomenon is of particular interest, since the chip temperature at the time of its separation from the workpiece, as well as the partial pressure of hydrogen near the surface, is too small for hydrogen to penetrate deep enough into the near-surface metal layers.

An important problem is the model of interaction of hydrogen with the metal directly in the region of rearrangement and rupture of bonding forces between atoms, which most adequately corresponds to the energy costs of opening a new surface, that is, the final manifestation of the influence of the medium on the cutting process.

It seems to us that the analysis within the framework of ideas about the chemical activation of media [4–8] and the experimental materials of our own research [1, 2] are sufficiently reliable to explain the differences in the reactivity of various substances and compounds, which are usually the components of LCTM.

The first difference is that the energy for breaking chemical bonds of low-molecular-weight organic compounds is much higher than that of high-molecular ones, which is caused by the following.

As already mentioned, the thermal decomposition of PE, whose macromolecules consist only of carbon and hydrogen atoms, occurs in the temperature range (290–350 °C), with the temperatures easily achieved in the cutting zone. At the same time, the pyrolysis of heptane, its analog model, whose molecule also consists of carbon and hydrogen atoms, begins at temperatures above 700°C, which does not always form in the cutting zone. If we compare, in comparative units, the value of the energy that needs to be spent to detach a hydrogen atom both in the PE macromolecule and the heptane molecule, it will be 3 and 11 units, respectively [3].

The second difference is related to the mechanism of molecular breakdown: low molecular weight organic compounds do not produce radically active products when the molecules are broken down, whereas in the first stage of the polymer macrochain breakdown, intermediate radical products are generated, the products being an additional source of the formation of new radically active substances. Moreover, their further chemical activation can acquire a self-accelerating and even avalanche-like character with an increase in new active particles, including those of ionized hydrogen [3, 5–7]. Note that in this case, at low pressures in the reaction zone, chain reactions develop at a finite constant rate without explosion (ignition).

It is extremely important to note that the presence of hydrogen both in the chips and in the surface being treated was recorded during the cutting of metal in any hydrogen-containing medium, even in water [1, 2]. However, the concentration of hydrogen in the metal when the latter is being processed in the medium with the addition of a polymer is approximately two orders of magnitude higher than in the low molecular weight medium. It is this fact that accounts for the significant advantage of LCTM with polymer additives associated with the specific thermal decomposition of the polymer macrochain. This makes it possible for the cutting zone to obtain a large concentration of a weakly ionized gas consisting of molecular and atomic hydrogen, as well as ions, radical ions, radicals.

Being an intermediate product, the activated hydrogen-containing gas mixture further penetrates into the reaction crack. Such a gas mixture continuously enters and accumulates in the space bounded by the crack tip, crack faces and the tool cutting edge.

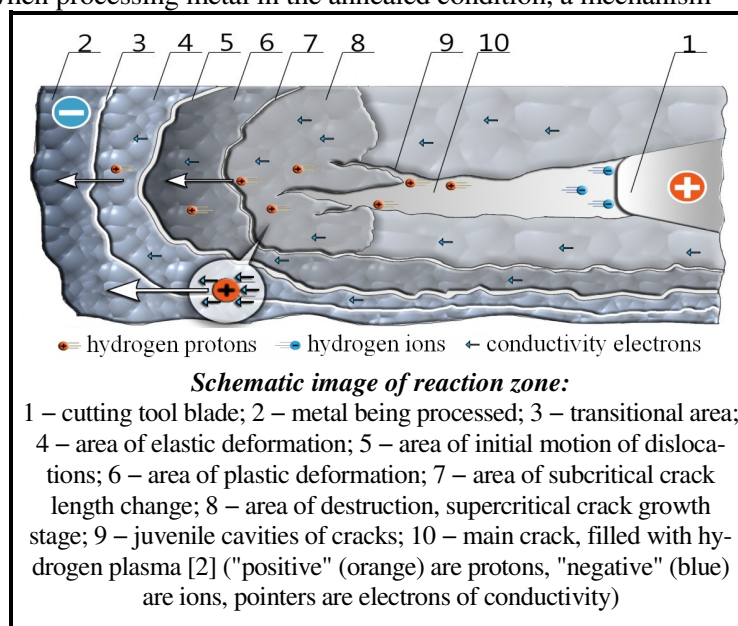
It is in this reaction zone that the final formation of a hydrogen plasma takes place. The ionizers of this process are juvenile catalytically active surfaces, exoelectronic emission, and self-accelerating gas-discharge processes.

The model of the reaction zone, presented below, is formed during the cutting process between the tool wedge and the ultramicroscopic region of the metal being processed in front of the crack tip, where high local stresses are concentrated, causing the formation and movement of dislocations, deformation of the material, formation of a microcrack grid and other defects [2].

Taking into account that the kinetics of moving the gas mixture from the hot surfaces of the chips and tool blade to the reaction crack is controlling its further activation processes, it is important to know about the micro and macroscopic peculiarities of the elementary processes of transporting hydrogen into the crack space. In this regard, we consider the situation that develops below the cutoff line, i.e. below the boundary between the highly deformable material (chips) and the remaining metal mass of the workpiece being processed.

When the area of the tool front surface is pressed, at high speed, into the localized area of the material being processed, a deformation occurs and propagates in the near-surface layer of the contact zone. It is known [9] that, when cutting at low speed, especially when processing metal in the annealed condition, a mechanism

with a developed plastic deformation zone is most likely. The material region being deformed becomes extremely non-uniform, penetrated by numerous nuclei of cracks and microcracks. When machining with high cutting speeds, the deformation mechanism along the shear planes becomes more acceptable. The emergence of a crack grid in this case is due to the displacement of the layers of material relative to each other, which is the result of a series of successive displacements of individual sections of the lattice along the crack planes. All these macro- and microscopic changes of the metal in the local zone being deformed during the mechanical processing of quasi-brittle metals are ways of accelerated penetration of the hydrogen gas mixture into the reaction crack.



The hydrogen gas mixture entering the crack space undergoes further transformations until the formation of a hydrogen plasma. The increase in the degree of ionization of the gas entering the crack occurs as a result of two parallel processes: the interaction of hydrocarbon compounds constituting the gas with catalytically active surfaces [2, 10] and the impact ionization of hydrogen molecules and atoms with electrons emitted at the time of the breakdown of the interatomic bonds of the body being deformed [2, 11]. Thus, when machining metal by cutting in a surface-active medium, the formation of new surfaces actually plays the role of a trigger device including the mechanisms for the occurrence of various physicochemical processes and phenomena whose interaction with the medium causes its self-activation up to the formation of a hydrogen plasma with an intensity of 6×10^3 pulses

per minute and the 10^2 eV energy of electrons emitted during the breakdown of interatomic bonds [12]. The experimental material obtained in the study of the interaction of various physicochemical processes and phenomena with the medium indicates the reality of the manifestation of a mechanoplasma effect in this case [1, 2].

Before considering the peculiarities of the processes of transporting hydrogen from the plasma to the metal fracture zone, it is important to note that the abundance and diversity of the material for studying the metal-hydrogen system clearly indicate that such displacement is possible only if hydrogen is in the proton state [13].

As already noted, hydrogen is always registered both in the chips and treated surfaces of workpieces of all metals, without exception, when the workpieces are cut in surface-active media. This means that such a transition of hydrogen is possible when, in the process of cutting, hydrogen protons under the action of an electric field created by a thermoelectromotive force acting in the machine-tool-workpiece system, move from the plasma in the crack space to the tool tip, and then penetrate the tool surface and diffuse into the ultramicroscopic region of the metal, where they affect the processes of restructuring and breaking bonds between the ions. At the same time, all the processes of transporting hydrogen to the main target, the metal fracture zone, occur at a rate exceeding the deformation rate.

Although hydrogen has an unusually high mobility in metals, its displacement, during the cutting process, with a tremendous speed exceeding several meters per second requires special consideration.

In the process of transporting the proton from the plasma to the metal fracture zone, three main stages can be distinguished: the movement of the proton in the crack space from the plasma to the workpiece surface zone being deformed, penetration under its surface at the crack tip and diffusion of hydrogen deep into the metal.

The transportation of hydrogen in the first stage (see the figure above) occurs as a result of the proton interaction with a negative electric charge, which is extremely concentrated in the ultramicroscopic region where the processes of rearrangement and rupture of interatomic bonds are carried out and, as already noted, is amplified by an electric field. The emergence of a concentrated charge is due to the fact that in the zone being deformed, with an increase in mechanical stresses, its effectiveness also increases. A heterogeneous, saturated with various defects material region at the crack tip impedes the movement of free electrons. That is why the capture of electrons by traps (defects) contributes to an increase in their concentration in the zone being deformed, which allows us to consider this region of material as having a concentrated negative electric charge.

Apparently, later, when the protons come in contact with the surface of the crack tip, the proton flux is divided into two parts. One moves freely under the surface, and then, transcrystallically, in the bulk of the metal. The other is captured by structural defects, cleavage steps and other electrically active surface elements involved in various physicochemical processes [14]. The most important reactions of ions on the surface include neutralization of protons, accompanied by the release of a significant amount of thermal energy (100 kcal/mol [15]). It is important to note that the neutralization products are in a state of high excitement and able to participate in further reactions, while also emitting thermal energy. Thus, due to the narrow focusing of the ionized hydrogen flux onto the surface of the crack tip (or fracture crack), it is possible to realize there a high density of thermal energy and, consequently, a parallel course of mechanical and thermal influence on the bonding forces between metal ions. The combined effect of mechanical and thermal energy on the bonding forces reduces them, disrupting the structure of the crystal lattice and, as a result, causes a loss of stability of the chemical compound, a decrease in its strength, and an increase in the processes of deformation and fracture.

With regard to the high rate of diffusion of hydrogen protons deep into the metal, it is apparently provided by an external electric field caused by the thermoelectric driving force, with the field creating conditions for the manifestation of the well-known electronic wind effect. The manifestation of this phenomenon is due to the fact that conduction electrons and hydrogen in the metal actually become bound to each other and, under the influence of the external electric field, continue joint displacement deep into the metal at high speed [16, 17]. In the process of ambipolar diffusion, from the stream of jointly moving electrons and hydrogen, some electron-ion formations will be captured by defects, i.e. traps concentrated in the bulk of the material. Most researchers believe that the trapping energy is quite large and amounts to several tenths of an electron-volt, which greatly exceeds the power of the electronic wind [14]. Consequently, during the displacement of hydrogen in the bulk of the metal, the large intensity of the force field, which is created by the electron shells of metal atoms, is able to hold some of the protons. In this connection, even a single γ – iron atom can bind up to 5 hydrogen protons [14], which means that the ability of an iron atom to hold a valence electron is weaker than the ability of a hydrogen proton to bind an electron. As a result, the proton of hydrogen binds an electron and forms an atom ($H^+ + e^- = H$),

and the reaction takes place with the release of high thermal energy. The group capture of protons by traps causes a concentrated heat release, which is so large that it can lead to the melting of local ultramicroscopic sections of the metal being deformed. Consequently, in the microvolume of the material, the thermal energy generated in connection with the contact interactions of electrically active hydrogen particles with an electrically active real metal structure increases the frequency of thermal vibrations of material atoms and the probability of their rupture. Acting in conjunction with the mechanical energy, they enhance the processes of deformation and fracture, and reduce the energy costs of cutting metal in various hydrocarbon LCTM.

Conclusion

The total energy costs of the process of machining metal by cutting can be significantly reduced if the process is carried out with constant flushing of a liquid containing a polymer of a certain property and concentration. Such a result is achieved due to additional thermal energy, which is formed in the material fracture zone in connection with the realization of the plasma effect.

The macroscopic form of the final manifestation of the surface-active medium influence on the processes of deformation and destruction of the metal during cutting must be associated not with the generally accepted interpretation of the adsorption decrease in strength, but with the transformation of the medium in the fracture zone into a radical-active plasma.

Further interaction of the positively charged hydrogen particles in the plasma composition with the electrically active real metal structure formed as a result of the mechanical action also affects the deformation and fracture of metal.

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Про вплив мастильно-охолоджувальних технологічних засобів на розрив металу в процесі різання

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Показано вплив мастильно-охолоджувальних технологічних засобів на руйнування металу в процесі різання. Встановлено, що найбільш ефективними присадками до мастильно-охолоджувальних технологічних засобів (МОТЗ) є аліфатичні граничні полімери – поліетилен і полівінілхлорид. В рамках уявлень про хімічну активацію середовища, а також проблем, що накопичилися з експериментальних матеріалів власних досліджень, проведені дослідження з якісного опису ускладнених моделей, пов'язаних з реальною мікроструктурою матеріалу і кількісними вимірами метало-водневих систем. Розглянуто різні аспекти проблем впливу механічної енергії та водню на перебудову кристалічної решітки і розриви сил міжатомних зв'язків, що виникають в ультрамікроскопічних областях. Висвітлено питання кінетики входу протона в глибину металу в системі метал–водень і його взаємодію з металом безпосередньо в області перебудови і розриву сил зв'язків між атомами на кінцевий прояв впливу середовища на процес різання. У статті описані процеси і явища, які проходять нижче кордону між сильно деформованим металом (стружкою) і решіткою маси металу оброблюваної заготовки та особливості процесів транспорту водню з плазми в осередок руйнування металу. Встановлено, що в мікрообсязі матеріалу теплова енергія, що утворюється через контактні взаємодії електрично активних частинок водню з електрично активною реальною структурою металу, збільшує частоту теплових коливань атомів матеріалу і ймовірність їхнього розриву. Діючи спільно з механічною енергією, вони полегшують процеси деформації та руйнування і знижують енергетичні витрати на різання металу в різних вуглеводневих МОТЗ. Відзначено, що присутність водню в стружці і в оброблювальній поверхні було зареєстровано під час різання металу в будь-якому водневмісному середовищі, навіть у воді. Однак концентрація водню в металі, під час його обробки в середовищі з добавкою полімеру, приблизно на два порядки вище, ніж в низькомолекулярному. Саме цей факт зумовлює значну перевагу МОТЗ з полімерними добавками.

Ключові слова: водень, метал, обробка, атом, протон, мастильно-охолоджувальні технологічні засоби (МОТЗ).

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