E3S Web of Conferences **471**, 05021 (2024) https://doi.org/10.1051/e3sconf/202447105021
TITDS-XIV-2023

Increasing oil absorption in bearings as a result of ultrasonic exposure to ultrafine particles

Sadokat Siddikova[1], *Shamilidin* Sirojidinov[2*], *Nasiba* Bakhriddinova[1], *Mokhira* Zaripova[1], and *Malokhat* Juraeva[1]

[1]Bukhara Engineering-Technological Institute, Bukhara, Uzbekistan
[2]Tashkent State Technical University, Tashkent, Uzbekistan

Abstract. The article proposes an approach that ensures an increase in oil absorption by bearings as a result of ultrasonic exposure to ultrafine particles. The approach is based on the method of thermodynamics and kinetics of the formation of inorganic ultrafine particles in liquid-phase processes. The work shows that one of the promising ways to improve the antifriction characteristics of bearing materials is the impregnation of porous hardened materials with oils with the addition of special solid carbon additives. The goal of the work is to develop an antifriction self-lubricating powder material that meets modern requirements for bearing units. The cavitation method is considered taking into account the impact action of liquid microjets. In this case, the ratio of the sizes of the cavitation bubble and the solid particle is taken into account. An increase in the effectiveness of the influence of ultrasonic waves on the oil absorption of the bearing material has been shown.

1 Introduction

Currently, there is a need to clarify certain provisions of the theory of hydrodynamic lubrication from the standpoint of using new lubricants in sliding bearings that have improved antifriction, antiwear and performance characteristics.

The development of modern branches of mechanical engineering is directly related to the solution of these problems, as the demand for products of the bearing industry is growing. These problems are noted in a number of review and scientific articles [1-4].

An analysis of literary sources shows that the use of various types of additives to improve the performance properties of lubricants has become one of the main directions in their development. The selection and use of additives for lubricants is a rather complex problem, and to successfully solve it, research is needed to assess the influence of additives on the rheological properties of lubricants and on the mechanical and physical properties of materials of contacting surfaces. Many properties of modern machines, characterized by high speed, accuracy, reliability and durability, depend on the technology for producing additives and methods of introducing them into lubricants [5-7]. The innovative bearing assemblies

---

* Corresponding author: oybektuyboyov85@gmail.com

and components created by the engineering industry, used in trucks, tractors, excavators, metal-cutting machines and tools, are striking examples of the success of not only diagnostics and controls, but also the effective use of lubricant compositions, which contain ultrafine or nanofine powders metals, oxides, polymers, carbon, diamond graphite, etc. [8-10].

One of the promising ways to improve the antifriction characteristics of bearing materials is the impregnation of porous reinforced materials with oils [11]. Special solid carbon additives are added to the oil to increase the amount of oil absorbed into the pores of the bearing material.

The use of new self-lubricating materials for the manufacture of parts and friction units is one of the most important tasks in the design of modern machine-building equipment [12-16]. The goal of the work is to develop an antifriction self-lubricating powder material that meets modern requirements for bearing units.

Since the coefficient of friction and wear intensity depend on the coefficient of pore filling with oil, determining the optimal modes and conditions of impregnation processes (creating the maximum possible open porosity, improving the properties of absorbed oil, developing impregnation modes) is a priority. This is the main step towards obtaining self-lubricating materials with consistently high anti-friction characteristics.

2 Materials and methods

Currently, the most widely and frequently used method of ultrasonic treatment. Ultrasound is elastic oscillations and waves in the frequency range 10^4-10^9 Hz. The speed of propagation of ultrasound in a material medium is determined by its characteristics such as elasticity and density. The propagation of high-power ultrasound in a physical medium - a liquid or a solid - causes a number of specific effects that are widely used in various branches of science and technology. With the help of ultrasound, the main technological process was significantly intensified, and qualitatively new indicators were obtained.

Ultrafine diamond-graphite material (UDG) was used as carbon additives for impregnation. To determine its optimal concentration in oil, its amount was varied. Impregnation was carried out in two ways - in hot oil and using ultrasonic vibrations. Industrial oil was used as the impregnating medium. As a result of the research, it was found that the maximum filling of pores with UDG particles occurs during the ultrasonic impregnation method. This occurs due to the energy released during the collapse of cavitation bubbles, as well as due to the interaction of particles moved by acoustic flows of various scales.

The process of ultrasonic exposure is influenced by all the main effects that occur in powerful ultrasonic fields. Due to ultrasonic action, oil with ultrafine additives penetrates into the pores of the material, filling them to the maximum.

3 Results

3.1 Cavitation process

Cavitation is a process of unstable change in the size of gas-vapor bubbles under alternating pressure in a liquid. This is explained by the fact that in liquids there are stably many tiny bubbles of micron sizes (from tenths to several microns), which are the nuclei of cavitation. The bubbles are filled with a dissolved gas, a vapor of a given liquid, and are concentrated on the walls of the vessels, on solid ultrafine particles suspended in the oil.

The emergence of gas-vapor bubbles is due to thermal fluctuations in liquids associated with external influences. These impacts include: a fairly high temperature of our planet (about 300 K on average), cosmic radiation, and others.

Under normal conditions, gas-vapor bubbles are in a liquid in a stable state, since the surface tension and hydrostatic pressure acting on a bubble of radius R_0 are balanced by the internal pressure of the gas-vapor mixture, which is determined by the expression:

$$P_n \;\; P_r = P_0 + (2\sigma/R_0), \qquad (1)$$

where P_n is saturated steam pressure; P_r is gas pressure; P_0 is static pressure; $2\sigma/R_0$ is surface tension.

When an ultrasonic field is applied to the oil, the cavitation nuclei lose their stability. Continuity is broken in the oil; gaps appear in the form of cavities. The resulting cavities begin to actively pulsate in the ultrasonic field, stretching in the wave stretching phase and shrinking in the compression phase. Pulsating cavities, if they are empty, are called cavitation, the process of development of the cavitation cavity in time is called ultrasonic cavitation. The value of the intensity of ultrasonic vibrations, at which the cavitation process occurs in the liquid, is called the cavitation threshold. The cavitation threshold depends on the physicochemical properties of the liquid and the frequency of ultrasonic vibrations.

For a liquid with a large surface tension coefficient σ and an increase in the static pressure P_0 in the volume of the liquid, the value of R_{cr} (R_{cr} is the critical radius of the bubble) increases, i.e., the cavitation process occurs at large sizes of the critical bubble radius R_{cr}. On the other hand, with an increase in sound pressure P_A and vapor pressure P_n inside the cavitation cavity, bubbles with lower R_{cr} values will cavitate.

Large gas-vapor bubbles are formed as a result of gas diffusion into a bubble from a liquid, coagulation of nuclei, liquid evaporation, and an increase in vapor mass. Such bubbles can reach resonant sizes; they are not involved in the cavitation process and, increasing in size, displace the liquid to the surface. It was found that with increasing frequency, the cavitation process is carried out by cavitation bubbles of smaller and smaller sizes, which do not have sufficient energy for cavitation effects on the material.

The greatest contribution to the increase in the intensity of cavitation is made by sound and static pressures. If one of these parameters is increased while keeping the second constant, then the cavitation intensity will increase to certain limited limits, after which it begins to decrease. As a result of studying these patterns, it was found that by simultaneously increasing both sound and static pressure, maintaining a certain ratio between them, it is possible to achieve a continuous increase in the intensity of cavitation. At the same time, the efficiency of the impact of ultrasound on the processes occurring in liquids also increases significantly.

The set of cavitation bubbles occupying a certain part of the liquid space is called the cavitation region. In clusters, the number of bubbles is large, while in the space between clusters it is small or may even be zero. The formation of the cavitation region begins with a single cavitation cavity, which collapses to give rise to new cavitation nuclei. Clusters are formed near the surface of the emitter, as well as at the liquid-solid interface, where, as always, as a rule, cavitation nuclei are present.

In the stage of compression of the cavitation cavity, the radial velocity rapidly increases and in a short time reaches a value comparable with the velocity of sound wave propagation in the liquid.

Under these conditions, we can assume that heat exchange with the external environment practically does not occur. The compression process is close to adiabatic, in which the work done during compression leads to a significant increase in internal energy. In this case, the temperature of the gas-vapor mixture inside the cavitation cavity rises sharply. Already in the initial phase of compression, the temperature exceeds the critical one (for example, for water +375 ^{0}C), when it becomes impossible to liquefy the gas even at high pressures.

In the final stage of compression, the vapor-gas mixture behaves like an ideal gas. As the compression increases sharply, the pressure and temperature inside the cavitation bubble. At the end of the compression phase of the wave and the beginning of the expansion phase, the bubble, compressed to high pressures, instantly expands similarly to a microexplosion. In the immediate vicinity of the cavitation bubble, a shock wave arises, caused by the collapse of the bubble. This allows the UDG particles, which find themselves in the zone of collapsing cavitation bubbles under the action of impacts, to penetrate deeper into the pores.

3.2 Impact action of liquid micro jets

Another possible mechanism for the penetration of particles into the pores of the material is associated with the impact action of liquid microjets formed before the collapse of cavitation bubbles.

The emergence of microjets is caused by the deviation of the bubble surface from a spherical shape. The development of each cavitation bubble does not occur in isolation, but in interaction with other bubbles located at close distances. In some cases, due to the proximity of the wall and the presence of pressure gradients, there is a general deformation of the shape of the bubbles and their flattening. In powerful ultrasonic fields, the vortex motions of the liquid create tensile stresses, which also contribute to the curvature of the bubble surface and the formation of depressions.

In the final stage of the collapse of the cavitation bubble, the liquid penetrates into the formed recesses in the form of microjets and penetrates the bubble at a speed of hundreds to several thousand meters per second (see Figure 1).

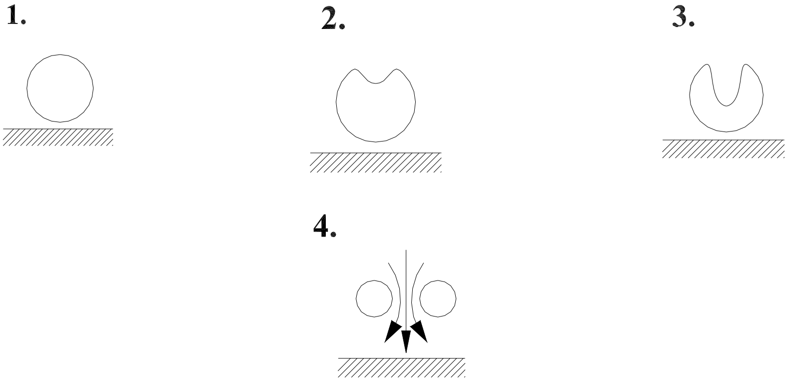

Fig. 1. Scheme of collapse of cavitation bubbles: 1 - initial spherical bubble; 2 - bubble flattening from the high-pressure side; 3 - formation of a depression; 4 - formation of microjets penetrating the bubble at high speed.

Fine powder particles located in the zone of collapse of the cavitation bubble during the impact action of microjets are entrained by the jets into the inside of the pore and can have kinetic energy sufficient to destroy acute-angled edges on the surface of solid particles, and in direct impact to destroy the particles themselves, which have structural defects.

Ultrasonic action is successful provided that the stress acting on the particle when the cavitation cavity collapses is lower than the real strength of the ultrafine powders used and the impregnated material.

As an example, diamond powders of the ACC brand can be cited. These diamonds are single crystals with a smooth surface and have a high real strength close to the theoretical one. In our case, the energy of collapsing cavitation cavities is insufficient for their destruction even at the optimal ratio of sound and static pressure. The impregnated material is also reinforced with UDG, which also indicates the preservation of the integrity of the samples obtained.

4 Conclusion

The predominance of one or another mechanism of action is determined by the ratio of the sizes of the cavitation bubble and the solid particle. If the cavitation bubble is smaller than a particle, it collapses with the formation of a microjet, otherwise, with the formation of a shock wave. It should be noted that the factors that determine the process of particle penetration into pores retain their significance in both models. The energy released during the collapse affects the solid particles of UDG. They penetrate deeper into the pores of the resulting samples, providing a better self-lubrication effect.

Due to the content of the optimal amount of UDG in the oil (about 3%), we were able to obtain a pore filling factor of 0.85. This indicates the effectiveness of the impact of ultrasonic waves on UDG, which significantly increases the oil absorption of the impregnated material and, accordingly, increases the service life of the obtained samples.

References

1. S.Q. Liu, Z. Lin, D. Li, X. Li, E. Kozan, M. Masoud, Mining **2**, 769-790 (2022). https://doi.org/10.3390/mining2040043
2. H. Fourie, Journal of the Southern African Institute of Mining and Metallurgy **116(3)**, 275-281 (2016)
3. A. Korotkov, L. Korotkova, D. Vidin, E3S Web of Conferences **402**, 10029 (2023)
4. M.V. Kipervasser, et al., IOP Conf. Ser.: Earth Environ. Sci. **823**, 012042 (2021)
5. P.B. Gerike, P.V. Yesherkin, Bulletin of the Scientific Center for Work Safety in the Coal Industry **2**, 65-72 (2020)
6. P.B. Gerike, Bulletin of the Kuzbass State Technical University **3(121)**, 126-134 (2017)
7. A. Korotkov, L. Korotkova, S. Voeth, R. Solentsov, E3S Web of Conferences **315**, 03019 (2021)
8. O.M. Batishcheva, A.V. Pylnova, V.G. Shuvaev, Proceedings of the International Symposium "Reliability and Quality" **2**, 102-103 (2011)
9. O.M. Batishcheva, A.V. Pylnova, V.G. Shuvaev, Proceedings of the Samara Scientific Center of the Russian Academy of Sciences **13(4-3)**, 962-965 (2011)
10. A.V. Pylnova, O.M. Batishcheva, Proceedings of the International Symposium "Reliability and Quality" **2**, 124-125 (2010)
11. D.C. Evans, G.S. Senior, Tribology International **15(5)**, 243-248 (1982)
12. M.V. Anikeeva, V.V. Kuznetsova, Bulletin of the Gomel State Technical University named after P.O. Sukhoi **2(69)**, 55-63 (2017)
13. B. Kasimov, M. Muminov, A. Abrorov, K. Mirzakarimov, Modern Innovations, Systems and Technologies **2(4)**, 0324-0330 (2022). https://doi.org/10.47813/2782-2818-2022-2-4-0324-0330
14. V.I. Vrublevskaya, M.V. Anikeeva, European research **6(17)**, 20-23 (2016)
15. X.L. Wang, L.Y. Yang, S.R. Wang, Advanced Materials Research **651**, 198-203 (2013)
16. M. Xodjiev, A. Djuraev, A. Ashurov, Modern Innovations, Systems and Technologies **2(3)**, 0201-0210 (2022). https://doi.org/10.47813/2782-2818-2022-2-3-0201-0210