



## **AGMA Technical Paper**

# **Application of a Unique Anti-wear Technology - Ion-Sulfurized Lubricating Gradient Material**

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

## Abstract

Ion-sulfurized lubricating gradient material (LGM), is a state-of-the-art technology conferring excellent anti-friction and wear-resistant characteristics on metallic parts including gears, splines, and bearings. It is characterized by a sulfur-proliferated zone composed of sulfides and sulfur-metal solid solution case with smooth sulfur compositional gradient inside the underlying bulk. A variety of metals and alloys, including steels, cast irons, super-hard alloys, and bronze, are suitable for ion-sulfurization. This treatment is carried out at low temperature; therefore, geometric integrity, microstructure and mechanical properties of the bulk are not compromised. It provides excellent solid lubrication which increases power efficiency and inhibits adhesive wear, seizure and scuffing in gears. Moreover, the micro-porous morphology in LGM's surface accommodates lubricating additives. It improves run-in efficiency of machinery/automotive units. The contact fatigue in gears and splines is noticeably reduced. The tribological property of the LGM layer on steel parts can survive an extraordinarily high temperature, which is rarely surpassed by other processes. With LGM, carbon/alloy steels can be used to substitute for certain copper alloys in manufacturing specific gears. It fulfills the requirement for maintaining stronger bulk while achieving superior friction/adhesion/run-in characteristics. In this article, the engineering characteristics of LGM technology are introduced, and exemplary applications are presented.

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## History of ion-sulfurized lubricating gradient material (LGM) technology

In modern industry, large fraction of machinery components, including gears, splines, and bearings, continually fall out of service because of wear and wear-related damages, along with which there is tremendous loss in raw materials, labor, and energy. Besides wear damages, friction consumes huge power share and decreases power transferring efficiency. Lubricating oil and grease can fail at a variety of conditions, which sometimes cause severe accidents [1]. Therefore, sound friction-reduction and wear-resistant technology is beneficial to economy, environment and safety. With such background, in 1980s, physicist Zhang Yifei developed the low-temperature physiochemical ion-sulfurization technology. In a vacuum environment, ionized sulfur diffuses into the metal, and a solid-lubricating case with composition gradient of sulfur is formed. Thus this technology is called ion-sulfurized lubricating gradient material (LGM) technology, or LGM technology, and the ion-sulfurization process is called LGM process. The LGM configuration is indicated in Figure 1, and the microscopic picture in cross section is shown in Figure 2. During the implementation and industrialization of this technology, substantial engineering advantages have drawn a constantly increasing attention.

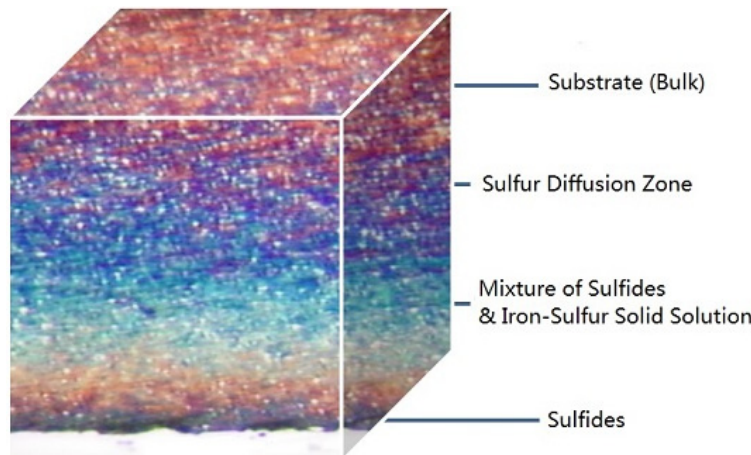


Figure 1. Indicative configuration of lubricating gradient material (LGM)

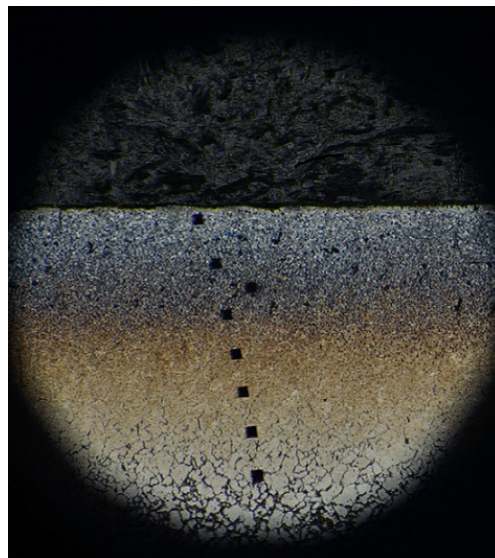


Figure 2. Microscopic picture of lubricating gradient material, ×120

## Characteristics of LGM

### Extraordinary tribological characteristics

The sulfides formed in LGM process possess hexagonal lattice structure and extreme lattice anisotropy, which contributes to low friction coefficient [2]. Owing to such characteristics, LGM technology increases power-transferring efficient and reduces friction heat. It also retards asperity welding and adhesive wear with insufficient or non-uniform lubricant, especially under high speed rolling and sliding condition. There are various surface processing mythologies that target acquiring advanced tribological properties on metallic parts, including physical or chemical depositing/bonding/spraying, and chemical diffusion process, like carburization and nitriding [3, 4]. LGM technology distinguished itself by forming a micro-porous friction-reduction layer.

Due to its micro porous feature (Figure 3), the LGM layer provides myriads of micro-reservoirs for lubricant agent and ensures hydrodynamic lubrication. Efficient lubrication alleviates seizure and galling and prevents premature failure. Furthermore, regular lubricants might fail under certain circumstances, such as chemical decay, emulsion instability, and foaming. Thus, solid lubrication effect of LGM layer functions as backup protection under unexpected lubricant deterioration. It is well recognized that high contact load in gears causes extreme-pressure malfunction in lubricant [5]. The LGM layer, however, mitigates shear stress in lubricant and compensates for the insufficient extreme-pressure additives.

Another noticeable engineering benefit of LGM is that it reduces run-in time, as it smoothes the part's surface via merging contact asperities.

The LGM processed article maintains a solid lubricating and wear-resistant surface, either at elevated-temperature or in radiating environment. Ion-sulfurized LGM in steel is able to maintain its lubricating property at a temperature even higher than phase transformation temperature of steel, while conventional lubricating grease only works up to 300°C (specific formula may survive a higher temperature), and molybdenum disulfides survive 315°C under non-vacuum environment [2].

LGM technology is being utilized in steel molds/dies in forming aluminum parts, due to the chemically inert characteristics of the sulfide layer. Figure 4 indicates that less damage was induced from service of LGM processed tools.

In regular dies, the chilling effect from the mold-releasing agents sets on hot fatigue cracks on surface. However, the sulfide layer allows for less amount of mold-release agent to be used, which inhibits the occurrence of this kind of cracks (Figure 5).

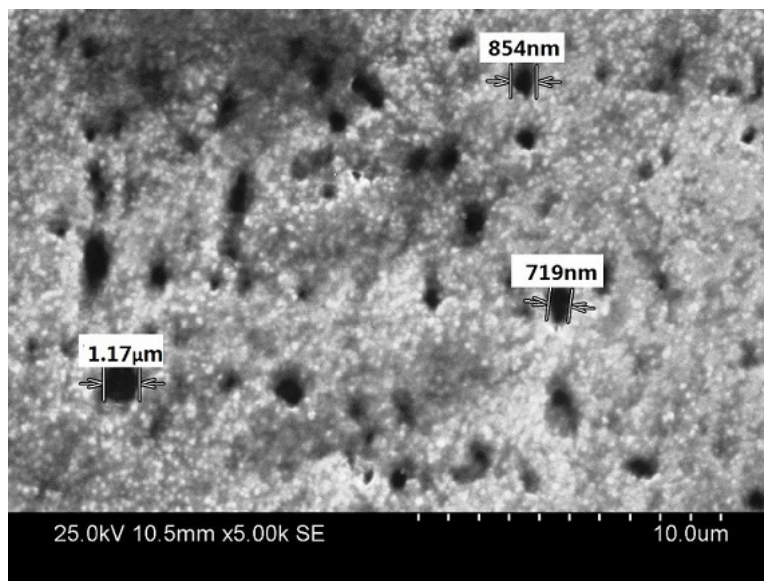


Figure 3. Micro porous feature of LGM's sulfide layer