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Research on Integrated Teaching of Science and Education in Engineering Materials Course Based on Properties of Babbitt Alloy

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Abstract: The course Fundamentals of Engineering Materials and Forming Technology was plagued by several prominent teaching limitations, including excessively abstract theoretical content, inadequate correlation between material microstructures and macroscopic properties, and a disconnection between forming processes and practical engineering service conditions. These issues led to fragmented knowledge systems among students and failed to fully cultivate students' engineering thinking and practical problem-solving competencies. Adhering to the educational philosophy of integrating scientific research with classroom teaching, this study adopted research findings on Babbitt alloy—a typical wear-resistant material for sliding bearings—as a core teaching carrier. The microstructure characteristics, performance regulation mechanisms, mechanical and tribological properties, and casting forming processes of Babbitt alloy were systematically integrated into classroom teaching. Accordingly, a closed-loop teaching module featuring the logical chain of "microstructure–hardness–tribological performance–forming process" was constructed. Combined with diversified teaching approaches, including problem-driven learning, case-based inquiry, and virtual-reality integrated teaching, the inherent drawbacks of traditional fragmented teaching were effectively addressed. This innovative teaching practice enabled students to clarify the intrinsic correlations among material microstructures, service performances, and forming processes, thereby significantly enhancing students' capabilities in mechanism analysis, process optimization, and engineering problem diagnosis. This study also provided a feasible practical reference for improving the teaching quality of fundamental engineering courses through the transformation and application of scientific research achievements.

1. Introduction

Fundamentals of Engineering Materials and Forming Technology is a compulsory core basic course for majors including Mechanical Design-Manufacturing, Intelligent Manufacturing and Materials Engineering. It undertakes the vital educational function of connecting basic material theories, forming technologies and engineering service applications, and serves as a core curriculum to cultivate students' cognition of engineering materials, process design and performance-optimization thinking. The core teaching objective is to help students establish a systematic materials-science thinking that "microstructure determines macroscopic properties, processing technology regulates tissue structure, and service performance matches working-condition requirements". Nevertheless, traditional teaching adopts fragmented chapter-based instruction, which separates material microstructure, mechanical properties, friction service characteristics and casting forming processes. It emphasizes conceptual memorization over mechanism analysis, and theoretical indoctrination over engineering application. Consequently, students can only recite scattered knowledge points, fail to analyze service-failure problems from material micro-characteristics, and struggle to optimize forming processes according to performance requirements, resulting in unsatisfactory cultivation of comprehensive engineering literacy.

As a critical special-purpose material for heavy-duty sliding bearings, Babbitt alloy is widely applied in high-end equipment such as steam turbines, internal-combustion engines and reducers[1,2]. Their casting processes and performance characterization provide excellent teaching cases linking microstructure, mechanical properties and wear-resistant service behaviors. Existing studies have demonstrated that the friction coefficient, wear-resistance life and service stability of Babbitt alloy are highly dependent on the morphology, grain size and distribution of the matrix and hard phases, while casting parameters constitute one of the key approaches to tailor microstructures and improve hardness and tribological properties[3-5]. Accordingly, this paper translates research achievements on Babbitt-alloy microstructure and tribological performance into classroom practice. Systematic teaching practice is carried out focusing on microstructure regulation, hardness-performance matching, friction-and-wear mechanisms and casting-process optimization, so as to realize in-depth integration of scientific research outcomes and curriculum teaching and remedy deficiencies in traditional instruction.

2. Major Problems in Current Curriculum Teaching

Traditional teaching is characterized by disconnection between micro-mechanisms and service performance as well as insufficient engineering pertinence. Material microstructure, mechanical hardness and friction-wear properties are delivered in isolated modules, failing to highlight the complete logical system of "composition-structure-performance-application". In chapters covering metallic microstructure, solidification phase transformation and material properties, the wear-resistant features and engineering applications are only briefly introduced, with direct conclusions of excellent mechanical properties given. The regulatory mechanisms of microstructure on material performances are not elaborated. Hence students can hardly understand performance differences induced by grain size, structural homogeneity and phase distribution, and their understanding of core metallic-material principles remains superficial. Meanwhile, existing teaching on wear failure is generally generalized, lacking targeted tribological knowledge for high-speed, heavy-load and oil-lubricated bearing conditions. Students tend to form the one-sided misconception that "higher hardness always means better wear resistance". They cannot comprehend the unique advantages of microstructure matching complex friction conditions, and have limited awareness of key engineering indicators such as friction coefficient, wear rate and

surface stability. Differences in performance regulation between ordinary structural materials and dedicated wear-resistant materials are poorly distinguished, leading to weak engineering logical thinking.

There lacks a closed loop between forming processes and service performance, which weakens students' engineering application competence. Chapters on casting mainly focus on procedures rather than mechanisms and practical applications. Instruction concentrates on casting principles, operational steps and defect identification, ignoring how casting parameters modulate microstructure, hardness and tribological service behaviors. Only basic features of gravity casting and centrifugal casting are presented, without establishing the teaching closed-loop of "process parameters-microstructure-wear resistance". Although students can memorize theoretical knowledge of various casting technologies, they are unable to reversely optimize key parameters such as pouring temperature, cooling rate and forming modes according to bearing wear-resistant service demands. Common deficiencies include "mastering process knowledge but misunderstanding mechanisms, being incapable of optimization and engineering implementation", and the systematic engineering thinking that processes serve service performance is severely insufficient.

3. Overall Design of Teaching Practice

Strictly complying with the curriculum syllabus, this teaching practice takes microstructure as the essential basis, tribological performance as the teaching core, casting technology as the regulation means, and engineering application as the cultivation goal to systematically reconstruct teaching logic and content. The conventional fragmented and isolated teaching mode is abandoned, and a complete teaching closed-loop is constructed around Babbitt-alloy microstructural features, structure-regulation mechanisms, hardness-matching rules, friction-and-wear mechanisms and casting-process optimization. The main thread runs as follows: the unique multiphase microstructure of Babbitt alloys determines their hardness and tribological properties; precise microstructure modulation can be achieved via composition adjustment and solidification-process optimization, so as to improve wear resistance, reduce friction loss and extend bearing service life. Following the concept of integrating scientific research with teaching and feeding research achievements back into classroom education, mature research outputs including metallographic characterization, friction-wear tests and process optimization of Babbitt alloy are transformed into teaching resources together with typical engineering cases. Abstract micro-mechanisms, performance-response rules and process-regulation principles are visualized and systematized into comprehensible, analyzable and applicable knowledge for students. Balancing theoretical depth, classroom adaptability and engineering practicability, this practice effectively fosters students' ability to analyze material mechanisms and optimize engineering processes.

4. Core Contents and Classroom Implementation of Teaching Practice

4.1. Casting Technology: Realization of Microstructure Regulation

Casting constitutes one of the core teaching contents, and serves as the key technical approach to tailor Babbitt-alloy microstructure, stabilize hardness and optimize tribological performances. This teaching practice emphasizes the correlation of "casting parameters-microstructure evolution-hardness indicators-tribological properties" to address the disconnection between processes and performances.

Parametric experimental teaching was carried out on mainstream Babbitt alloy forming processes.

1) Pouring temperature: Too low temperature induces misrun and microporosity, reducing matrix

compactness and hardness and raising wear rate; excessively high temperature causes abnormal grain coarsening, more oxidized inclusions and severe hard-phase segregation, introducing friction-surface defects and poor service stability. 2) Solidification cooling rate: Rapid solidification enhances undercooling to refine grains and uniformly disperse hard phases, improving hardness uniformity and friction stability. Slow cooling leads to grain growth and elemental segregation, degrading microstructure homogeneity and causing large fluctuations in tribological properties. 3) Forming process comparison: Relative to conventional gravity casting, centrifugal casting removes pores, shrinkage cavities and inclusions, yielding dense, uniform microstructures and significantly improving hardness stability and wear life of Babbitt alloy.

4.2. Microstructure regulation: unraveling the essential origin of tribological properties

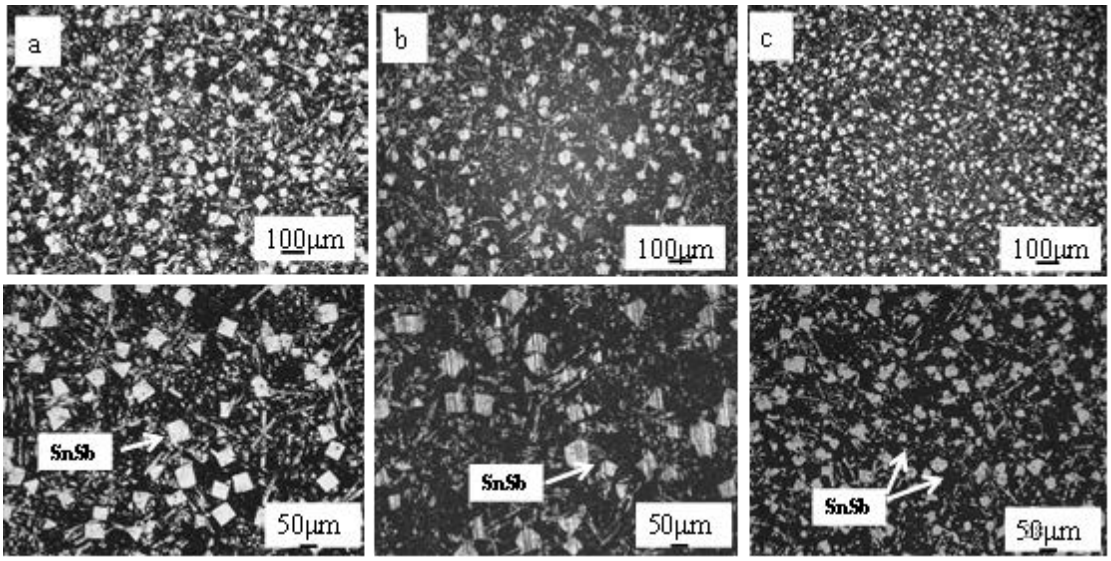


Figure 1 Microstructure of Babbitt alloys under optical microscope: (a) bare Babbitt, (b) heated Babbitt, (c) modified Babbitt

Microstructure constitutes the core internal factor determining the tribological properties of Babbitt alloy, and it is also a key-and-difficult section in the chapter “Relationship between Material Microstructure and Properties”. Based on existing research findings, the conventional basic-theory teaching is optimized and upgraded, with special teaching focusing on the microstructure of Babbitt alloys. The classroom emphasizes analyzing the microstructure of tin-based Babbitt alloy (ZCHSnSb11-6), which consists of a tin-rich α-solid-solution matrix together with rhombic SnSb and acicular Cu_6Sn_5 intermetallic compounds as hard phases. Standard metallographic images and microstructure comparisons (see Figure 1) are adopted to visually demonstrate the microstructural characteristics of Babbitt alloy: hard phases are uniformly and dispersedly distributed within the continuous and dense soft matrix. Meanwhile, comparative cases of defective microstructures are introduced to present coarse-grained and fine-grained morphologies, enabling students to directly distinguish high-quality microstructures from defective ones.

Knowledge points regarding modifying Babbitt alloy by adding rare-earth La to regulate their microstructure are integrated from research achievements to deepen classroom teaching [6]. Grain refinement and improved distribution uniformity can be effectively realized by fine-tuning alloy composition, melt modification treatment and solidification-rate control. After modification, SnSb grains are significantly refined. Accordingly, stress distribution inside Babbitt alloy becomes more homogeneous, which greatly restrains plastic flow, stress concentration and local spalling during

friction, and improves wear resistance. This teaching module helps students firmly establish the core understanding that “microstructure directly determines tribological service stability”, and addresses the difficulty of abstract theoretical knowledge in this course.

4.3. Hardness and Friction-Wear Mechanism: Establishing a Microstructure-Dominated Cognitive System for Tribological Performance Evaluation and Failure Analysis

Hardness exerts a direct influence on material wear behaviors(see Figure 2, 3). Insufficient hardness weakens the deformation resistance of the matrix, aggravates plastic wear, increases material loss and shortens service life remarkably. Excessively high hardness reduces material toughness; microcracks and brittle spalling tend to occur under alternating frictional loads, triggering fatigue wear failure. Performance-matching criteria can be established according to practical engineering service conditions. Babbitt alloy with uniform microstructure and moderate hardness are suitable for high-speed and light-load conditions, whereas alloys with reasonable hard-phase proportion and excellent hardness stability are preferred for heavy-load and low-load conditions. Students are guided to develop the thinking of matching working conditions, microstructure and mechanical properties.

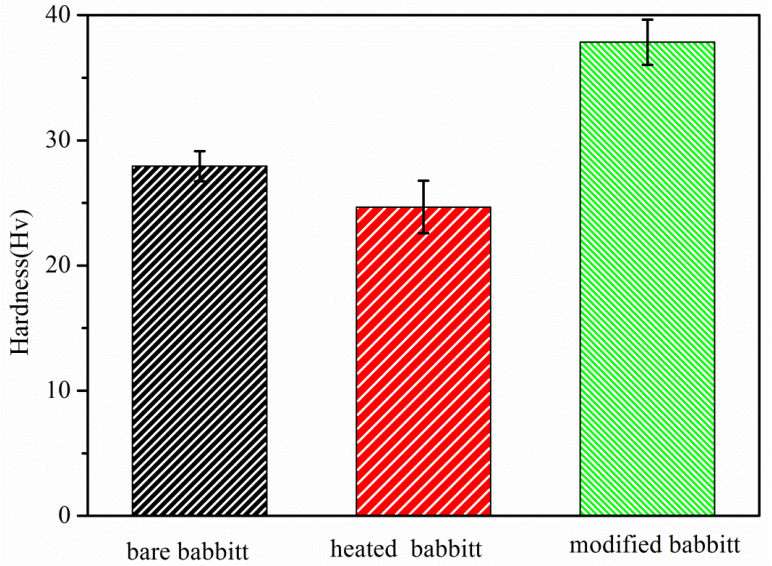


Figure 2: Microhardness of different specimens

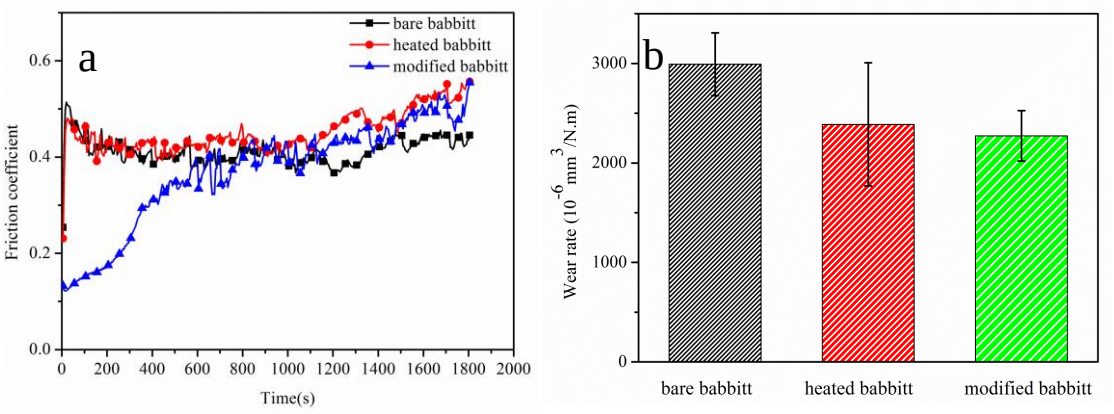


Figure 3: Tribological properties of different specimens under dry-friction condition: a) friction coefficient curves, b) wear rate

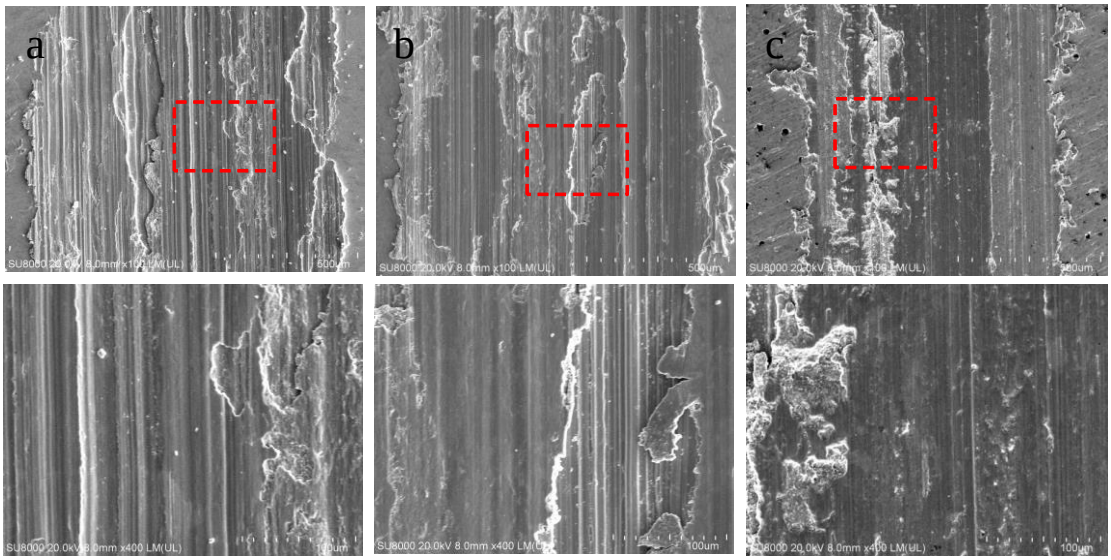


Figure 4: Worn surfaces of different specimens under dry-friction condition: a) bare babbitt, b) heated babbitt, c) modified babbitt

On this basis, drawing on textbook knowledge of material wear and failure analysis as well as tribological research outcomes of Babbitt alloy, the microstructure-dominated wear-resistant mechanisms and failure rules are further revealed(see Figure 4). During friction, the soft matrix of Babbitt alloy undergoes controlled slight plastic deformation and forms a dense and stable friction transfer film on contact surfaces, which isolates direct metal-to-metal contact and reduces friction coefficient. Correlative analysis of typical engineering failure cases establishes the internal relationship between micro-defects and macroscopic wear failure. Non-uniform hard-phase distribution and loose microstructure result in local insufficient hardness and severe abrasive wear. Structural defects such as coarse grains and inhomogeneous microstructure readily initiate fatigue cracks under alternating loads and bring about surface spalling failure. Imbalanced proportion between matrix and hard phases aggravates interfacial adhesion and tearing wear. Consequently, students can systematically interpret hardness response, friction-wear behaviors and engineering failure causes from the perspective of microstructure, and acquire comprehensive capabilities for analyzing material service performance and judging engineering problems.

5. Conclusion

Based on research achievements concerning microstructure and tribological properties of Babbitt alloy, this paper carries out targeted teaching practice for the course *Fundamentals of Engineering Materials and Forming Technology*. Centering on four core dimensions: microstructure, performance matching, frictional service performance and process regulation, a novel teaching system integrating scientific research and education is constructed. By translating cutting-edge research outputs into classroom teaching resources, the barriers between micro-mechanisms and macroscopic properties, theoretical knowledge and process practice, classroom learning and engineering application are effectively broken through. This work aims to address existing teaching problems including fragmented knowledge, disconnection between theory and practice, and insufficient engineering thinking. This teaching mode conforms to the educational law of engineering basic courses. It can improve teaching quality and students' comprehensive engineering literacy, and provide feasible practical references for teaching reform and transformation of research findings in similar basic material-related courses.

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