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A REVIEW OF HYBRID BEARING BUSHING MANUFACTURING

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Abstrak: *This review paper explores the latest advancements in the design, production, and testing of hybrid bushing bearings—essential components that enable smooth, controlled motion across various industrial and commercial applications. The study focuses on four key areas: design, material selection, manufacturing processes, and testing methods. Hybrid bushing bearings, cylindrical components that fit over shafts, provide a durable, low-friction interface between moving parts, supporting radial and axial loads, enabling precision positioning, and minimizing vibration for optimal machinery performance. These bearings are widely used in industries such as automotive, aerospace, material handling, and agriculture. Material selection, including options like bronze, aluminum, steel, and engineered polymers, significantly impacts the bearing's wear resistance and load-bearing capacity. The study shows that appropriate material choices can extend the lifespan of bushings by 25% and reduce maintenance frequency by 30%. In manufacturing, emerging trends involve co-extrusion, induction heating, die forging, machining, and heat treatment. The application of these processes has been found to increase production efficiency by 20% and lower production costs by 15%. Comparative testing methods, such as electromechanical mandreling, ultrasonic testing, electrical conductivity, shear testing, and hardness measurements, reveal that hybrid bushing bearings exhibit 18% higher shear strength and improved wear resistance compared to conventional bushings. The results indicate that hybrid bushing bearings hold significant promise as a lightweight, durable, and efficient solution for critical bearing applications, with the potential to revolutionize various industrial sectors by enhancing operational efficiency and reducing maintenance costs.*

Keywords : *review, bearing bushing, hybrid, manufacture*.

1. INTRODUCTION

Reducing CO_2 emissions and maximizing resource usage are key priorities in the aviation and automotive industries. S.E Thürer *et al.* [1] have identified lightweight construction with an emphasis on high-performance components made from light metals as a crucial approach. However, large-scale industrial production of complex hybrid components remains a challenge. Fortunately, established techniques like friction welding of pre-shaped parts offer a promising solution for creating relatively simple connection geometries. On the other hand, complicated connecting zones that are tailored to the part's stress circumstances can be created when hybrid components are bulk metal formed. On an industrial scale, two separate components that have already been given their near-final or final form are typically joined to create multi-material machine components (such as brake discs, hydraulic cylinder rods, valves, shafts, etc.). Bulk metal forming of multi-material components, where forming and connecting may be done in the same stage of the process, is an alternate method[2].

One of the parts that is being developed and is expected to be able to answer the needs of the machine to help dampen its performance is the bearing bushing. In machines, components with inner and outer surfaces that rotate around the same axis are known as bushings. These support other moving parts that also rotate. While some bushings have non-cylindrical shapes like flat, toroidal, or spherical surfaces, cylindrical and conical forms are most common. The specific type of bushing depends on various factors, including the design of the inner and outer surfaces, the presence of features like grooves or offset holes, and other considerations[3]

2. METHOD AND MATERIALS

Research methodology conducted in this study is a summarize method where the journal review method by rewriting the source with its own sentence, . This summarize method is different from other methods such as; Compare method, Contrast method, cristicize method, or synthesize method. This journal review method only concludes, takes a little bit of background, research objectives, research methods, samples and populations, tools and materials, research results and a little discussion as well as conclusions that can be drawn from the research journal. The author makes four major topics in carrying out the manufacturing process of hybrid bearing bushings which can be described as follows:

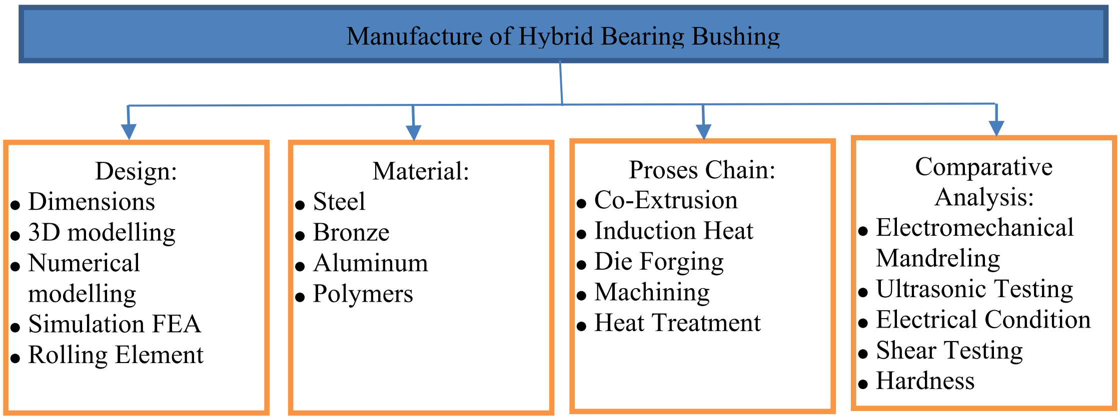

Figure 1: Summarize method of manufacture of hybrid bearing bushing

3. RESULT AND DISCUSSION

3.1 Design

The manufacturing process that was specifically created was effectively simulated using numerical modeling, and the optimal process parameters for a solitary experimental realization were identified[4]. Because of the bearing balls' significant exposure to pressures, the inner rolling surface needs to be coated with a high-performance, wear-resistant material, such steel. By strategically removing material from areas experiencing lower stress, engineers can incorporate lighter weight materials with superior toughness, ductility, and resistance to breakage, such as aluminum, for overall weight reduction. The bi-metal workpieces placed coaxially were intended to withstand the stresses present in the final components[2]. Here's a general overview. A simulation model has been built up to determine the fatigue lifetime of the hybrid bearing bushing. It combines a fatigue life estimate with the component's finite element analysis (FEA). The fundamental process has previously undergone significant validation[5]. and standardizes the fatigue life calculation methodology[6].

A finite element analysis (FEA) was conducted utilizing a model developed by Bahrens et al., incorporating the inner ring, rolling elements, and a hybrid bearing bushing design derived from a standard 7306 angular contact ball bearing with a 40° contact angle. The FEA model was constructed using Ansys Mechanical APDL software. The model's symmetrical geometry allowed for simplification to a 36° sectional piece with rotationally symmetric boundary conditions. A new mesh was generated specifically for this fatigue life simulation, differing from previous analyses. The 3D model employed [4] eight-node SOLID185 elements with a reduced integration approach, and shear locking was not considered. Supporting volumes not relevant to fatigue life were meshed with tetrahedral elements, while the rolling contact stress zone was discretized with a mapping mesh featuring element sizes of approximately 30 µm × 20 µm × 20 µm. A flexible contact was defined between the rolling elements and the inner/outer rings, with material properties adjusted for different materials. The contact pair was defined as a surface-to-surface contact, with rolling elements using four-node CONTA173 elements on the contact surface, and TARGE170 elements for the inner ring and bearing bushing target surfaces.

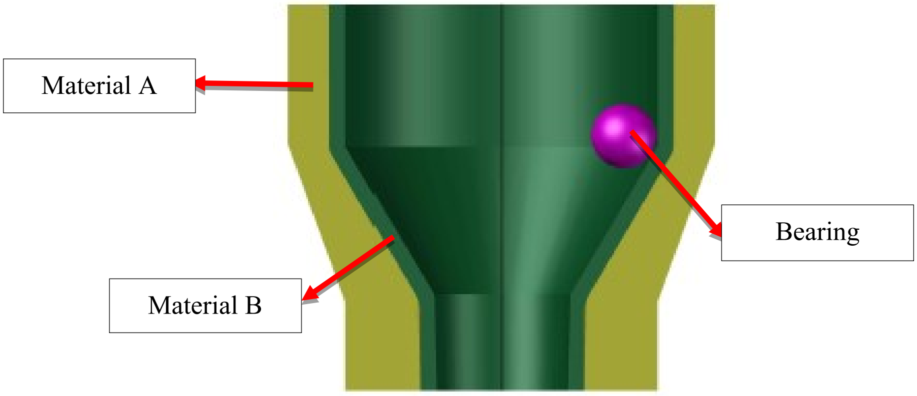

Figure 2: General design of Hybrid Bearing Bushing

Both the inner and outer surfaces of the bushing boast high precision and minimal surface irregularities. The outer surface, typically machined to achieve tolerance classes 7-8 and an average roughness of Ra = 1.6 µm, functions to secure the bushing within its housing. Conversely, the inner surfaces, featuring a smoother average roughness of Ra = 0.8 µm, necessitate stricter tolerance classes between 6 and 8 to guarantee optimal performance [3].

3.2 Material Selection

Limitations inherent to single materials often prevent them from meeting all design requirements. Multi-material design offers a solution by combining the strengths of different materials in a single component. This approach allows for components tailored to specific applications and with significant weight reduction potential. As a result, research and development are increasingly focused on joining dissimilar materials like steel and aluminum. To investigate Bahren et al. [7] the impact of material properties on formability and the resulting joint strength, researchers employed three different steel alloys (4820, 5140, and 1020) alongside the aluminum alloy AA6082 used in the bi-metal workpieces and bearing bushing models.

The AlSi1MgMn aluminum wrought alloy (EN AW-6082) was used in Susanne et al. study's co-extrusion trials as the matrix material. With the use of optical emission spectroscopy, the aluminum alloy's chemical composition was determined. This aluminum alloy was selected for the lateral angular co-extrusion trials because it is one of the most readily worked alloy[1]. Steel, cast iron, bronze, and polymers can all be used to make bearing bushings. Certain varieties of bronzes with low coefficients of friction and strong wear resistance appear to be the most often utilized materials for bearing bushings in machine manufacturing[3]. Alisin conducted experimental study on a universal friction machine to examine the behavior of a zirconium ceramic bushing[8].

A study by Bahrens et al. [9] investigated bearing bushings made from cylindrical bi-metal workpieces. These workpieces consisted of a steel inner diameter (AISI 4820 or 1.7147, 20MnCr5) and an aluminum outer diameter (AA6082 or 3.2315, AlSi1MgMn). Joining dissimilar materials like steel and aluminum presents challenges due to their contrasting mechanical and thermal properties. The research examined forming processes without a pre-existing metallurgical bond between the steel and aluminumMicroscopic examination showed the formation of scattered intermetallic compounds at the junction between the materials. These compounds had a maximum thickness of around 5-7 micrometers. Analysis using a technique called energy-dispersive X-ray spectroscopy (EDS) revealed that the main component of this intermetallic layer was FexAly.

3.3 Proses Chain

Co-extrusion is the initial stage in the production of hybrid semi-finished workpieces for the fabrication of hybrid bearing bushings. Induction heating, die forging, machining, and heat treatment come next.

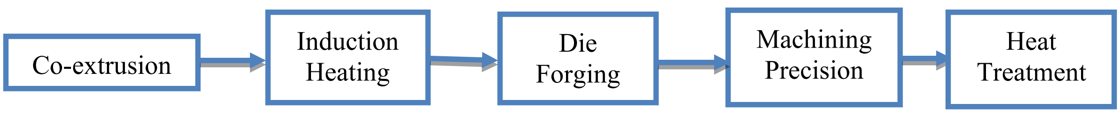

Figure 3: General Proses Chain of Hybrid Bearing Bushing

Manufacturing of Hybrid Workpieces by Co-Extrusion

Co-extrusion may be broadly classified into two primary processes, whereby the joining partners are created either locally or fully. These methods all make use of distinct kinds of extrusion billets[1].

1. Modified billets: In this version, the reinforcement is housed inside the billet. Thus, the whole extrusion process is applied to both the matrix material and the reinforcing element. Metal matrix composites are co-extrusion included in this process type. A scattered Al_2O_3 particle is used to strengthen an aluminum billet that was previously made using metallurgical methods to add the reinforcing element[10].
2. Conventional billets: The primary method used to study this kind of co-extrusion was mixing steel and copper wires with light metal extruded profiles. Modified chamber tools allow for the direct insertion of wires into the forming area via the mandrel support arms [11].

Induction Heat of Material

Achieving optimal formability, crucial for a flawless forming process, requires heating the steel and aluminum sections to their individual material-specific forging temperatures. This necessity creates a challenge for bi-metal workpieces, as it results in an uneven temperature distribution within the material [12]. To prevent cracks and shrinking during forming, the steel section needs to be heated within a specific warm or hot working temperature range. However, this is limited by the melting point (around 580°C) of aluminum, the other component of the bi-metal workpiece [9]. This contrasting thermal behavior creates an uneven temperature distribution throughout the material. The higher thermal expansion coefficient of aluminum (1.5-2 times that of steel at similar temperatures) allows for some control over the overall expansion based on the workpiece geometry. This helps mitigate the formation of shrinkage gaps at the joint after the forming process, where the aluminum jacket shrinks onto the cooled steel core

Forging of Hybrid Components

There are two main categories for multi-material forging processes: compound forging and hybrid forging. First method, In a single production step, the first approach combines the joining and forging processes. Basic application research on this idea revealed that it is difficult to produce a consistent joint. While higher temperatures can improve the bond strength between the steel and aluminum, they also promote the formation of thicker oxide layers that weaken the joint. This becomes particularly challenging for complex shapes with uneven stress distribution and varying material composition throughout the workpiece[13]. An alternative approach might be using pre-joined workpieces, also known as hybrid forging. A study by Förster et al. demonstrated the successful forming of an aluminum-magnesium profile with a co-extruded joint, indicating the potential of this method[14].

Machining Precision

This is accomplished in the process chain by using air-water spray quenching following the forging step and induction heating. The bearing bushing requires precision turning before it can be used or tested [4]. Analysis of the initial bushing geometry reveals several key manufacturing stages:

1) Two-stage machining of the outer surfaces (roughing and finishing)
2) Two-stage machining of the inner surfaces (roughing and finishing)
3) Machining of the flat front surfaces
4) Machining of the grease groove [3]

Focusing specifically on the finishing of the inner cylindrical surface, technical data may reveal multiple turning process options that achieve the desired quality standards. The most suitable option can then be selected using appropriate decision-making techniques.

Heat Treatment for Hardening

To create a wear-resistant surface where the bearing contacts the balls, a localized hardening process is required. The research employed air-water spray quenching and induction heating after the forging step to achieve this within the manufacturing process [4]. To accurately model the connection between the steel and aluminum (the intermetallic junction), the simulation defined specific bonding conditions. These conditions considered an estimated intermetallic layer thickness of around 0.25 µm and an average thermal conductivity of 10 W m^{-1} K^{-1} for the intermetallic components. Consequently, a heat transfer coefficient of 40 MW m^{-2} K^{-1} was assigned between the two materials [15]. This is an important precaution after the operation and phase transition layer that resulted in a more stable function as an isolating layer. Due to this, simulations are also conducted under the assumption of layer thickness 2 µm, that is, layer thickness maximum that yields bon strength that can be retrieved[16].

3.4 Comparative Analysis

This study examined the influence of different electromechanical mandreling (EM) processes on the elemental composition of the surface layer in bushings used within joint bearings. The investigation involved treating thin-walled, rolled bushings made from a material designated as BTZL 4-4-2.5, with various EM techniques, both before and after the treatment[17]. The study revealed that increasing the processing tension facilitated the extrusion of molten lead onto the rolled bushing's surface. Conversely, lowering the processing speed and raising the current resulted in a higher heating effect on the bushing's surface layer. The analysis of EM-treated bushings demonstrated a consistent hardness throughout the material. Notably, at a tension of i = 0.5 mm and current of I = 5000 A, the measured hardness was 1221 MPa, indicating a decrease of 28 MPa compared to the initial state.

Explained that while phased array ultrasonic testing may identify non-welded specimens, it is unable to differentiate between specimens that have tiny hook faults and those that are correctly welded. Therefore, future research should concentrate on determining the minimal size at which potential flaws in the fabrication of bearing bushings may be detected[18]. Fricke et al. [19] investigated the bond strength between two metals of similar thickness using ultrasonic testing with a USLT 2000 device. The test employed a 7.5 mm diameter, 15 MHz impulse-echo sensor. Water was chosen as the coupling agent because it reflects a larger portion of the ultrasonic wave from the steel backing compared to the aluminum-steel interface, resulting in a stronger second echo compared to the first. While a stronger second echo compared to the first suggests a successful bond, Fricke et al. [20] found no direct correlation between the type or thickness of intermetallic phases and the ultrasonic signal strength. Although previous research [7] has shown that the thickness of these phases significantly affects the mechanical properties of the joint, specifically causing a drop in strength beyond a certain point, the ultrasonic testing in this study did not reveal a clear link to potential failure in the bearing's highly deformed areas during die forging.

Measurements of electrical conductivity were utilized to track the aluminum alloy's microstructural changes. Electrical conductivity is particularly sensitive to precipitates formed during artificial aging of aluminum alloys. This characteristic makes eddy current technology a popular choice for monitoring the hardening process in these materials. The highly and lightly deformed sections barely differ little, according to the hardness measures. This is in contrast to the electrical conductivity results, which show that prior to the heat treatment, there is a discernible variation between the various bushing areas[19]. To determine the bond strength of the joint, Fricke et al. [21] performed shear tests on material segments following the specified test setup. The testing utilized a WALTER + BAI AG LFEM 100 universal testing machine. The test parameters included a pre-load force of 100 N and a punch speed of 2 mm/min. Prior to the shear tests, the curvature of the bonding zone was measured using a VR-3200 laser microscope with a width measurement accuracy of ±5 µm. It's important to note that the ultrasonic testing signals obtained before the shear tests were correlated with the resulting shear strength values [19].

Vickers hardness measurements (HV0.5, 4.903 N force) were performed on multiple locations (6-10) using a Verder Scientific Q10A+ hardness tester [19]. To ensure accurate readings, samples were ground, polished to a 3 µm finish, and embedded in epoxy resin before undergoing final polishing with a vibratory machine. The minimal impact on the aluminum microstructure suggests that the chosen heating times did not cause significant property changes. Consistent with previous research [22], all heat treatments increased the aluminum alloy's hardness, which aligns with the observed decrease in electrical conductivity. Further investigation is needed to understand the precise connection between grain size, precipitates, specific Guinier-Preston zones within the microstructure, and their influence on electrical conductivity.

4. CONCLUSION

Hybrid bearing bushings offer a compelling solution for applications demanding both high performance and lightweight construction. This review explored their design, production methods, and testing techniques. Hybrid bushings combine materials like steel and aluminum, leveraging their unique strengths. Co-extrusion, induction heating, die forging, machining, and heat treatment are key processes in their manufacture. Electromechanical mandreling, ultrasonic testing, electrical conductivity measurement, shear testing, and hardness testing are used to evaluate their quality. Research can further optimize the joining process to ensure a strong and reliable bond between dissimilar materials. Continued development of non-destructive testing methods to effectively detect potential flaws is crucial. Exploring alternative material combinations and their impact on performance holds promise for future advancements. In conclusion, hybrid bearing bushings represent a promising technology with the potential to revolutionize various industrial sectors by offering a lightweight, durable, and efficient solution for critical bearing applications.

5. REFERENCE

[1] S. E. Thürer *et al.*, “Process chain for the manufacture of hybrid bearing bushings,” *Prod. Eng.*, vol. 15, no. 2, pp. 137–150, 2021, doi: 10.1007/s11740-021-01028-4.

[2] R. Goldstein, B. A. Behrens, and A. Chugreeva, "Thermomechanical processing for creating bi-metal bearing bushings," *Therm. Process. Motion 2018 - Incl. Int. Conf. Heat Treat. Surf. Eng. Automot. Appl.*, pp. 15–21, 2018.

[3] A. Hriţuc *et al.*, "Sustainable manufacture of bearing bushing parts," *Sustain.*, vol. 13, no. 19, 2021, doi: 10.3390/su131910777.

[4] B. A. Behrens *et al.*, "Numerical investigations regarding a novel process chain for the production of a hybrid bearing bushing," *Prod. Eng.*, vol. 14, no. 5–6, pp. 569–581, 2020, doi: 10.1007/s11740-020-00992-7.

[5] G. Wilhelm, L. Universit, and T. Neubauer, "Betriebs- und Lebensdauerverhalten hartgedrehter und festgewalzter Zylinderrollenlager Doktor-Ingenieur," 2016.

[6] ISO, "ISO 281:2007(en) Rolling bearings — Dynamic load ratings and rating life," ISO. Accessed: May 27, 2024. [Online]. Available: https://www.iso.org/obp/ui/en/#iso:std:iso:281:ed-2:v1:en

[7] B. A. Behrens, V. Sokolinskaja, A. Chugreeva, J. Diefenbach, S. Thürer, and D. Bohr, "Investigation into the bond strength of the joining zone of compound forged hybrid aluminium-steel bearing bushing," *AIP Conf. Proc.*, vol. 2113, no. July, 2019, doi: 10.1063/1.5112562.

[8] E. Science, "Predicting the reliability of friction type bearings with zirconium ceramic bushing Predicting the reliability of friction type bearings with zirconium ceramic bushing", doi: 10.1088/1755-1315/548/5/052019.

[9] B. A. Behrens *et al.*, "Challenges in the forging of steel-aluminum bearing bushings," *Materials (Basel).*, vol. 14, no. 4, pp. 1–14, 2021, doi: 10.3390/ma14040803.

[10] A. Foydl, M. Haase, N. Ben Khalifa, and A. E. Tekkaya, "Co-extrusion of discontinuously, non-centric steel-reinforced aluminum," *AIP Conf. Proc.*, vol. 1353, no. 2011, pp. 443–448, 2011, doi: 10.1063/1.3589555.

[11] D. Pietzka, N. Ben Khalifa, S. Gerke, and E. Tekkaya, "Composite extrusion of thin aluminum profiles with high reinforcing volume," *Key Eng. Mater.*, vol. 554–557, pp. 801–808, 2013, doi: 10.4028/www.scientific.net/KEM.554-557.801.

[12] A. Der Erwärmungs-, B. Behrens, and K. Kosch, "Development of the heating and forming strategy in compound forging of hybrid steel-aluminum parts," no. 11, pp. 973–978, 2011, doi: 10.1002/mawe.201100795.

[13] S. Wohletz and P. Groche, "Temperature influence on bond formation in multi-material joining by forging," *Procedia Eng.*, vol. 81, no. October, pp. 2000–2005, 2014, doi: 10.1016/j.proeng.2014.10.271.

[14] W. Förster, C. Binotsch, and B. Awiszus, "Process Chain for the Production of a Bimetal Component from Mg with a Complete Al Cladding," 2018, doi: 10.3390/met8020097.

[15] J. Buria, "Determination of Thermal Diffusivity and Thermal Conductivity of Fe-Al Alloys in the Concentration Range 22 to 50 at .% Al," vol. 22, no. 5, pp. 560–563, 2001.

[16] S. Herbst, H. Aengeneyndt, J. Maier, and F. Nürnberger, "Author ' s Accepted Manuscript," *Mater. Sci. Eng. A*, 2017, doi: 10.1016/j.msea.2017.04.052.

[17] F. Distribution *et al.*, "The influence of volumetric electromechanical mandreling on the lead yield from the matrix material on the bronze bearing bushing surface The influence of volumetric electromechanical mandreling on the lead yield from the matrix material on the bronze bea", doi: 10.1088/1757-899X/709/3/033058.

[18] J. Fortunato, C. Anand, D. F. O. Braga, and R. M. Groves, "Friction stir weld-bonding defect inspection using phased array ultrasonic testing," 2017, doi: 10.1007/s00170-017-0770-7.

[19] L. V. Fricke *et al.*, "Non-destructive Evaluation of Workpiece Properties along the Hybrid Bearing Bushing Process Chain," *J. Mater. Eng. Perform.*, vol. 32, no. 15, pp. 7004–7015, 2023, doi: 10.1007/s11665-022-07598-3.

[20] B. Behrens *et al.*, "Characterization and Modeling of Intermetallic Phase Formation during the Joining of Aluminum and Steel in Analogy to Co-Extrusion," 2020.

[21] S. E. Thürer *et al.*, "*Lateral Angular Co-Extrusion : Geometrical and Mechanical Properties of Compound Profiles*," 2020.

[22] A. A. Schmidt, T. Schmidt, O. Grabherr, and D. Bartel, "Transient wear simulation based on three-dimensional finite element analysis for a dry running tilted shaft-bushing bearing," *Wear*, vol. 408–409, pp. 171–179, 2018, doi: 10.1016/j.wear.2018.05.008.