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MECHANICAL ANALYSIS ON HEAVY DUTY ROLLER

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Abstrak

Analisis mekanikal merupakan aspek penting dalam rekayasa yang bertujuan untuk memahami penyebab utama kegagalan komponen dan mengembangkan strategi untuk mencegah terjadinya di masa depan. Tesis ini menyajikan analisis kegagalan menyeluruh pada roller tugas berat yang digunakan dalam aplikasi industri, dengan fokus pada identifikasi mekanisme yang menyebabkan kegagalan dini. Roller tugas berat mengalami kondisi operasional ekstrem, termasuk beban tinggi, kecepatan yang bervariasi, dan faktor lingkungan yang keras, yang membuatnya rentan terhadap keausan dan kegagalan. Studi ini melibatkan pemeriksaan mendetail terhadap sampel roller yang gagal menggunakan berbagai teknik analisis, termasuk inspeksi visual, analisis metalurgi, mikroskop elektron pemindai (SEM). Hasilnya mengungkapkan bahwa mekanisme kegagalan utama adalah kelelahan, keausan abrasif, dan pelumasan yang tidak memadai. Kegagalan kelelahan ditandai oleh adanya retakan mikro yang berkembang seiring waktu akibat beban siklik. Keausan abrasif diidentifikasi melalui pemeriksaan topografi permukaan, yang menunjukkan bahwa partikel yang terjebak di antara permukaan bergulir menyebabkan penghilangan material yang signifikan. Selain itu, pelumasan yang tidak memadai ditemukan memperburuk kelelahan dan keausan dengan meningkatkan gesekan dan stres termal. Analisis ini juga menyoroti beberapa faktor yang berkontribusi terhadap mekanisme kegagalan ini, seperti cacat material, inkonsistensi manufaktur, dan praktik pemeliharaan yang tidak memadai. Analisis metalurgi menunjukkan adanya inklusi non-logam dan perlakuan panas yang tidak tepat sebagai faktor signifikan yang mengkompromikan integritas material. Rekomendasi ini mencakup peningkatan pemilihan material, proses perlakuan panas yang dioptimalkan, strategi pelumasan yang lebih baik, dan protokol pemeliharaan yang ketat. Implementasi rekomendasi ini diharapkan dapat secara signifikan mengurangi tingkat kegagalan dan memperpanjang masa operasional roller tugas berat di lingkungan industri. Studi ini menekankan pentingnya pendekatan sistematis terhadap analisis kegagalan dan menyediakan kerangka kerja untuk menangani masalah serupa pada komponen kritis lainnya. Wawasan yang diperoleh dari penelitian ini berkontribusi pada bidang rekayasa keandalan yang lebih luas dan memiliki implikasi praktis bagi industri yang bergantung pada sistem roller tugas berat.

Kata kunci: analisis kegagalan; analisis metalurgi; keausan abrasif; kelelahan; pelumasan; rekayasa keandalan; roller tugas berat

Abstract

Mechanical analysis is a critical aspect of engineering that aims to understand the root causes of component failures and develop strategies to prevent future occurrences. This thesis presents a comprehensive failure analysis of heavy-duty rollers used in industrial applications, focusing on identifying the mechanisms that lead to their premature failure. Heavy-duty rollers are subjected to extreme operational conditions, including high loads, varying speeds, and harsh environmental factors, making them prone to wear and failure. The study involved a detailed examination of failed roller samples using various analytical techniques, including visual inspection, metallurgical analysis, scanning electron microscopy (SEM). The results revealed that the primary failure mechanisms were fatigue, abrasive wear, and improper lubrication. Fatigue failures were characterized by the presence of micro-cracks that propagated over time due to cyclic loading. Abrasive wear was identified through the examination of surface topography, indicating that particles entrapped between rolling surfaces led to significant material removal. Additionally, improper lubrication was found to exacerbate both fatigue and wear by increasing friction and thermal stresses. The analysis also highlighted several contributing factors to these failure mechanisms, such as material defects, manufacturing inconsistencies, and inadequate maintenance practices. Metallurgical analysis indicated the presence of non-metallic inclusions and improper heat treatment as significant factors compromising the material integrity. These include material selection enhancements, optimized heat treatment processes, improved lubrication strategies, and rigorous maintenance protocols. Implementing these recommendations is expected to significantly reduce the failure rate and extend the operational lifespan of heavy-duty rollers in industrial settings. This study underscores the importance of a systematic approach to failure analysis and provides a framework for addressing similar issues in other critical components. The insights gained from this research contribute to the broader field of reliability engineering and have practical implications for industries relying on heavy-duty roller systems.

Keywords: abrasive wear; fatigue; failure analysis; heavy-duty rollers; lubrication; metallurgical analysis; reliability engineering

1. Pendahuluan

The industrial landscape relies heavily on the seamless functioning of heavy-duty rollers, critical components that facilitate the movement and transportation of substantial loads in diverse sectors such as construction, mining, and manufacturing **[1]**. These rollers, often employed in conveyor systems, machinery, and other heavy-load applications, serve as linchpins in optimizing material handling processes **[2]**. A heavy-duty roller is a robust component designed to withstand significant mechanical stresses and environmental conditions, commonly used in industrial settings such as hot strip mills to facilitate the processing of materials **[3]**.Understanding the complexities associated with the performance and failure of these heavy-duty rollers is imperative for ensuring operational efficiency, minimizing downtime, and safeguarding investments in industrial infrastructure.

Heavy-duty rollers are essential components in the machinery and systems that underpin numerous industrial processes. Their significance lies in their ability to efficiently transport heavy loads, reduce friction, and ensure the smooth operation of material handling equipment. The reliable performance of heavy-duty rollers directly influences overall productivity, operational costs, and the longevity of industrial equipment **[4]**. Therefore, a systematic investigation into the factors affecting the reliability and functionality of heavy-duty rollers holds substantial importance for industries aiming to enhance their competitiveness and sustainability. Material defects are inherent flaws or irregularities within a material, such as inclusions, voids, or micro-cracks, that can significantly impact the performance, wear resistance, and longevity of components, often leading to premature failure **[5]**.

Heavy-duty rollers are engineered to minimize friction during material transport. By providing low-resistance surfaces, these rollers enable the seamless movement of goods and materials **[4]**. This friction reduction not only enhances energy efficiency but also contributes to the longevity of equipment components, reducing wear and the need for frequent maintenance. Fatigue wear is the process of material degradation that occurs when repeated cyclic stresses cause the initiation and propagation of cracks, leading to surface flaking or spalling and eventual component failure **[6]**.

2. Bahan dan Metode Penelitian

A tensile test, also known as a tension test, is a fundamental mechanical test in which a material specimen is subjected to a controlled tension until failure. A specimen is deformed, usually to fracture, with a gradually increasing tensile load that is applied uniaxially along the long axis of a specimen **[7]**. The purpose of this test is to determine the material's tensile strength, yield strength, elongation, and other mechanical properties under uniaxial loading conditions. During the test, a sample of the material is gripped at both ends and pulled apart at a constant rate, while the force and the elongation of the specimen are measured. The results provide critical information about the material's behavior and performance in applications where it will experience stretching or pulling forces. This data is essential for material selection, quality control, and predicting how materials will react under various types of loads in real-world applications.

A hardness test on materials is a method used to determine a material's resistance to deformation, typically by indentation. Brinell tests have long been the preferred method of assaying the hardness of metals during forming operations **[8]**. Hardness testing provides valuable information about a material's strength, wear resistance, and ductility. The test involves pressing a hard indenter into the surface of the material under a specific load and measuring the size or depth of the resulting indentation.

A composition test, often referred to as a chemical composition analysis, is a method used to determine the elements and compounds present in a material and their respective quantities **[9]**. This type of test provides detailed information about the material's chemical makeup, which is crucial for understanding its properties, performance, and suitability for specific applications. Composition tests are widely used in material science, metallurgy, manufacturing, and quality control.

3. Hasil dan Pembahasan

Metallurgical analysis testing encompasses a diverse range of methods, each serving specific purposes in evaluating the properties and behaviour of metals and alloys that has been tested. Here's an explanation and the result of the testing which is used. This is a fundamental mechanical test that applies a tensile load to a standardized specimen until it fractures. During the test, strain (deformation) is measured relative to the initial length of the specimen, and stress (force per unit area) is calculated based on the applied load and the specimen's cross-sectional area.

Table 1 Tensile Strength Data

Specimen	Sample Code	Area (mm2)	Ultimate Force (N)	Ultimate Stress Mpa	Offset Force @0.2% N	Offset Stress @0.2% (Mpa)	Modulus Elastisitas (Gpa)	Total Elongation (%)
1	Round Bar (E 36.2)	123	85700	697	49000	400	200	22

As the table above, The Ultimate Stress of 697 MPa indicates the maximum amount of stress the Round Bar (E 36.2) can withstand before fracturing. The Offset Yield Stress of 400 MPa represents the stress at which the material exhibits a permanent deformation of 0.2%. The Modulus of Elasticity (200 GPa or 200,000 MPa) reflects the stiffness or rigidity of the material. The Total Elongation of 22% signifies the material's ability to deform plastically before fracturing. The graph of stress and strain can be viewed as below.

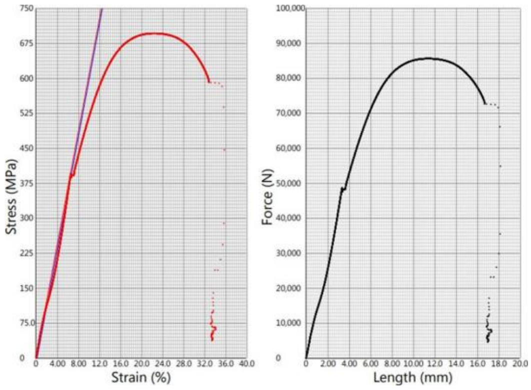

Figure 1 Tensile Test Graph Result

The hardness test gives the results as shown in the table below:

Table 2 Hardness Test Result

Position	Hardness Test Result (Brinell)
1	263.4
2	270.4
3	255.2
4	265.5
5	272.5
6	260.5
7	256.5
8	249.6
9	260.6
10	249.5
Rata-rata (HB)	260,37

The hardness values range from 249.5 HB to 272.5 HB across the 10 test positions. The average Brinell hardness number (HB) for the Round Bar (E 36.2) is 260.37 HB. Consistency in hardness values is important for ensuring uniform mechanical properties throughout the material. Deviations from the average hardness might suggest areas of interest for further investigation, such as localized variations in material properties or potential surface anomalies.

The data outlines the concentration of various elements in the material. The percentages represent the content of each element in the material, and the weight percentages provide the amount of each element per 100 grams of the material.

Table 3 Chemical Composition Result

Unsur Element	Kadar (%) Content (wt.%)	Unsur Element	Kadar (%) Content (wt.%)
C	0,502	Nb	<0,001
Si	0,313	Pb	0,02
Mn	0,762	Sb	< 0,005
P	<0,001	Sn	0,01
S	< 0,005	Ta	<0,02
Cr	0,939	La	0,003

Unsur Element	Kadar (%) Content (wt.%)	Unsur Element	Kadar (%) Content (wt.%)
Mo	0,155	Ti	0,0002
Ni	0,057	V	0,0014
Cu	0,166	W	< 0,005
Al	0,022	Zn	0,0054
As	0,0035	Zr	0,0005
B	< 0,0001	Se	< 0,001
Bi	<0,0072	N	0,089
Ce	< 0,002	Ca	< 0,0001
Co	0,012	Te	<0,001
Mg	0,0022	Fe	96,93

4. Kesimpulan

The primary failure mechanisms for heavy-duty rollers likely include surface wear and abrasion, fatigue cracking, corrosion, impact and deformation, and thermal fatigue. The material composition and mechanical properties suggest that while the rollers are designed for high strength and durability, the identified failure mechanisms reflect the challenging operational conditions these components face. Addressing these mechanisms through material selection, heat treatment, surface coatings, and regular maintenance can enhance the rollers' performance and lifespan.

Material defects, manufacturing inconsistencies, and operational conditions all play a crucial role in the failure of heavy-duty rollers. Material defects such as impurities and non-uniform microstructures can initiate cracks and weaken the material. Manufacturing inconsistencies, including uneven heat treatment and surface defects, further exacerbate these weaknesses, creating areas prone to failure. Operational conditions, particularly cyclic loads, corrosive environments, and temperature fluctuations, stress the material and can lead to the propagation of existing cracks and defects. Addressing these issues requires a comprehensive approach involving stringent quality control in material selection and manufacturing processes, as well as careful consideration of the operational environment to mitigate potential failure mechanisms and enhance the durability and performance of the rollers.

SEM plays a critical role in metallurgical analysis by providing detailed microstructural and compositional insights. It helps identify and analyze failure mechanisms such as wear, fatigue, inclusions, and phase distributions. By integrating SEM findings with hardness and tensile test data, a comprehensive understanding of material behavior and failure can be achieved, leading to improved material performance and reliability in heavy-duty applications.

By implementing these design modifications and maintenance practices, the reliability and lifespan of heavy-duty rollers can be significantly enhanced. Key strategies include optimizing material selection and heat treatment processes, applying protective coatings, ensuring proper lubrication, conducting regular inspections, and using predictive maintenance techniques. These measures collectively address the primary failure mechanisms identified from the data, such as wear, fatigue, and corrosion, leading to improved performance and durability of heavy-duty rollers.

5. Daftar Pustaka

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