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Failure Mechanism Identification of Hook Components in Automatic Machines Using Visual and Material Analysis

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ABSTRACT

The hook component in automatic packaging machines frequently experiences premature failure, leading to increased downtime, higher maintenance costs, and reduced production efficiency. This study aims to identify the failure mechanism of the hook through visual inspection, maintenance data analysis, and material characterization. Visual examination was conducted on broken hook specimens to identify fracture morphology and surface characteristics. Historical maintenance records from 2017 to 2024 were analyzed to identify the frequency and type of failure. Chemical composition testing was performed using Optical Emission Spectroscopy (OES), while Rockwell hardness testing (HRC) evaluated the material's mechanical properties. The results revealed that the failure mode was categorized as brittle fracture, indicated by flat and granular fracture surfaces without plastic deformation. The main failure factor was the direct impact between the hook and the punch, caused by misalignment due to bearing wear. The material, classified as medium carbon steel with 0.599 wt.% C and 1.000 wt.% Mn, exhibited high hardness but low toughness, leading to a brittle fracture under impact loading. Surface hardening combined with light tempering and shot peening is recommended to improve wear resistance and toughness, thereby reducing the risk of brittle fracture.

Keywords: Brittle Fracture, Carbon Steel, Hook Failure, Impact Load, Material Analysis, Visual Inspection

ABSTRAK

Komponen hook pada mesin pengemasan otomatis sering mengalami kegagalan dini, yang menyebabkan meningkatnya waktu henti produksi, biaya perawatan yang tinggi, serta penurunan efisiensi proses. Penelitian ini bertujuan untuk mengidentifikasi mekanisme kegagalan hook melalui pemeriksaan visual, analisis data perawatan, dan karakterisasi material. Pemeriksaan visual dilakukan pada sampel hook yang patah untuk mengidentifikasi morfologi dan karakteristik permukaan patahan. Data perawatan historis periode 2017 hingga 2024 dianalisis untuk menentukan frekuensi dan jenis kegagalan yang terjadi. Pengujian komposisi kimia dilakukan menggunakan metode *Optical Emission Spectroscopy* (OES), sedangkan uji kekerasan Rockwell (HRC) digunakan untuk mengevaluasi sifat mekanik material. Hasil penelitian menunjukkan bahwa mode kegagalan yang terjadi tergolong patah getas (brittle fracture), yang ditandai dengan permukaan patahan datar dan granular tanpa deformasi plastis. Faktor utama penyebab kegagalan adalah benturan langsung antara hook dan punch akibat ketidaksejajaran (misalignment) yang disebabkan oleh keausan pada bearing. Material hook yang diklasifikasikan sebagai baja karbon menengah dengan kadar 0,599 wt.% C dan 1,000 wt.% Mn memiliki kekerasan tinggi tetapi ketangguhan rendah, sehingga mengalami patah getas akibat beban kejut. Disarankan untuk menerapkan perlakuan pengerasan permukaan (*surface hardening*) yang dikombinasikan

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dengan temper ringan dan shot peening untuk meningkatkan ketahanan aus dan ketangguhan material sekaligus mengurangi risiko patah getas.

Kata kunci: Analisis Material, Baja Karbon Menengah, Beban Kejut, Kegagalan Hook, Patah Getas, Pemeriksaan Visual

1. Introduction

Automatic industrial machines rely heavily on precision components to ensure continuous and efficient operation. Among these components, the hook mechanism plays a crucial role in gripping and maintaining the integrity of the packaging cycle. However, frequent hook failures have been reported, often requiring replacement two to three times per year. Such a high failure rate results in increased machine downtime, higher maintenance costs, and reduced production reliability, indicating that the hook represents a weak point in the mechanical system.

Mechanical failure is defined as a change in the size, shape, or structural properties of a material or machine component that prevents it from performing its intended function properly [1]. The most fundamental causes of component failure include design incompatibility, improper material selection, manufacturing or assembly errors, unexpected operating conditions, and inadequate maintenance practices [2].

Based on field observations, the hook failed two to three times annually, exhibiting a sudden fracture without any plastic deformation. This indicates the occurrence of brittle fracture behavior. Fracture is a mechanical failure event in which a component separates into two or more parts [3]. The types of fracture are generally classified into ductile and brittle fracture. Brittle fracture is characterized by little or no plastic deformation, a bright granular fracture surface, and a reflective appearance. This type of failure commonly occurs in materials with high hardness but low toughness [4].

Similar phenomena were reported by Geng et al. [5], who analyzed a hook component in an automatic friction-welding machine that failed due to multi-source fatigue caused by excessive stress concentration at small chamfer radii, machining marks, and carbide segregation. Such conditions accelerate crack initiation and propagation, reducing the service life of the component.

Several studies have emphasized that premature failure of mechanical components in automatic machinery is frequently associated with improper alignment, impact loading, and inadequate material toughness. Misalignment caused by bearing wear or assembly inaccuracies can generate unexpected impact stresses, leading to sudden brittle fracture even under nominal operating loads [6]–[8].

Material selection also plays a crucial role in determining failure behavior. Medium carbon steels are commonly used for load-bearing machine components due to their high strength and wear resistance; however, excessive hardness without adequate tempering significantly reduces fracture toughness and impact resistance [9], [10]. Previous failure analyses have shown that components made of hardened medium carbon steel are particularly susceptible to cleavage fracture when subjected to shock loading or stress concentration [11].

Despite extensive studies on fatigue-related failures, limited research has focused on brittle fracture induced by impact loading in hook-type components of automatic packaging machines. Therefore, this study addresses this gap by combining visual inspection, historical maintenance data analysis, and material characterization to identify the dominant failure mechanism and its root cause.

2. Methods

This research method is descriptive and analytical, using a failure analysis approach to identify failure modes in hook components. The research was conducted in four stages, as shown in the flowchart in Figure 1.

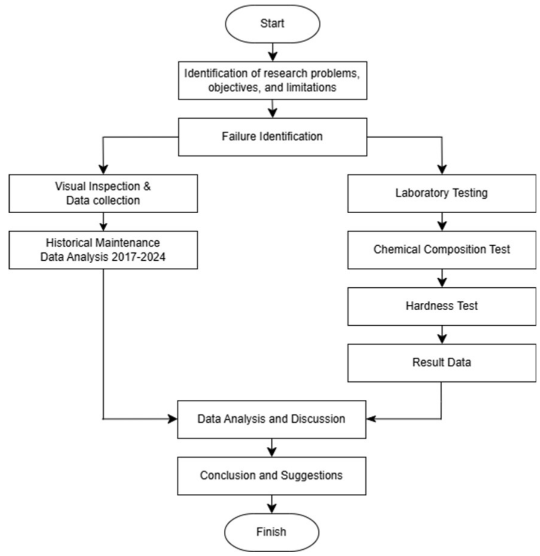

Figure 1. Research flowchart.

2.1. Visual Inspection

The fractured hooks (shown as Figure 2) were examined using the naked eye to identify fracture characteristics such as flatness, texture, and presence of deformation or striations. This observation provided an initial understanding of the fracture mechanism.

Figure 2. Sample hook.

2.2. Historical Maintenance Data

Maintenance records from 2017 to 2024 were analyzed to determine the frequency, duration, and interval of failures (Time to Failure and Time to Repair). Patterns were then correlated with possible operational factors contributing to premature failure.

2.3. Chemical Composition Test

Optical Emission Spectroscopy (OES) was used to analyze elemental composition and compare it with AISI 1060 standards. The test followed ASTM E415-08, identifying the main alloying elements: carbon, manganese, silicon, phosphorus, and sulfur.

2.4. Hardness Test

Rockwell hardness testing type C (HRC) was conducted using a diamond cone indenter (120°) according to SNI 8388:2017. This test determined the hardness level and its correlation with material brittleness.

3. Result and Discussion

3.1. Visual Inspection

Two fractured hooks, designated as Sample A and Sample B (shown in Figure 3), were analyzed. Based on earlier fractographic studies, the nature of fracture (ductile, brittle, or fatigue) can be determined by analyzing fracture surface morphology in top and side views, where features such as dimples, striations, and cleavage facets serve as key indicators [12]. The examination included observing the fracture surface, top view, and side view of the component, which can indicate whether the failure is brittle, ductile, or due to cyclic loading (fatigue).

Figure 3. Sample hook.

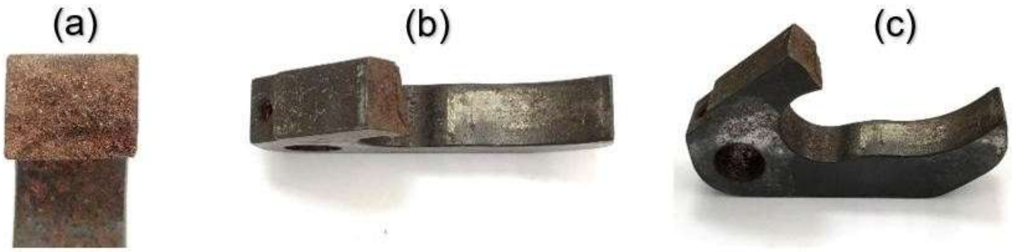

Figure 4. Sample A, (a) fracture surface detail, (b) top view, and (c) side view.

Visual observation of Sample A (shown in Figure 4) revealed a flat, granular fracture surface parallel to the cross-sectional plane of the material, with no necking or signs of plastic deformation around the fracture area. The fine-grained surface texture and the absence of beach marks indicate that the crack propagated rapidly and uniformly through the metal's crystal planes, without gradual crack growth.

The top view shows that the fracture surface is flat and parallel to the cross-sectional axis, with no signs of bending or stretching of the metal fibers at the fracture edge. The fracture line is also distinct and relatively straight, indicating that crack propagation occurred rapidly through the crystal planes, rather than through gradual growth. Similarly, the side view shows that the fractured portion has a flat surface and a sharp fracture angle.

Figure 5. Sample B, (a) fracture surface detail, (b) top view, and (c) side view.

Visual observation of Sample B (shown in Figure 5) revealed a flat, granular fracture surface that appeared perpendicular to the direction of the force. There were no signs of plastic deformation such as necking or stretching of the material around the fracture area, indicating that the failure process occurred suddenly and without warning. The rough, shiny, irregular granular surface indicates that the crack propagated rapidly through the metal's crystal planes, indicating a cleavage fracture mechanism common in materials with low ductility or in brittle conditions due to thermal treatment or shock loading. Furthermore, the position of the threaded hole at the top could potentially be a stress concentration point that triggered crack initiation.

The top view shows that the fractured portion did not experience significant bending or displacement. The metal surface around the fracture area shows a sharp transition between the intact and fractured portions, with no signs of necking or plastic stretching. The slightly shiny metal surface on some sides indicates minor friction between the surfaces during the rapid cracking process. Similarly, from the side view, the fracture surface contours appear flat and parallel, exhibiting no curved or stepped patterns. The geometry is also intact and shows no significant plastic deformation around the fracture edges.

Based on visual inspection of both samples, both Sample A and Sample B exhibit typical characteristics of brittle fracture. The fracture surface appears relatively flat and perpendicular to the loading direction, with a granular texture and no signs of plastic deformation around the fracture area. No beach marks or gradual crack growth patterns typically seen in fatigue fractures were observed. These characteristics indicate that failure in both samples occurred suddenly due to momentary tensile or flexural stresses exceeding the material's strength, causing the crack to propagate rapidly without warning. Such fracture characteristics are consistent with cleavage-dominated brittle fracture commonly observed in hardened steels subjected to impact or shock loading [13], [14].

3.2. Historical Maintenance Data

Table 1. Hook component TTR and TTF data.

No	Actual Start	Condition	Component	TTR (minute)	TTF (h)
0	23-Nov-18	Damaged	Hook	70	0
1	14-Dec-18	Broken	Hook	45	168
2	21-Mar-19	Broken	Hook	45	776
3	09-Aug-19	Broken	Hook	240	1128
4	16-Aug-19	Worn	Hook	15	56
5	19-Aug-19	Broken	Hook	80	24
6	15-Jul-20	Broken	Hook	30	2648
7	22-Dec-20	Broken	Hook	120	1280
8	28-Dec-20	Worn	Hook	60	48
9	20-May-21	Broken	Hook	120	1144
10	16-Jun-21	Broken	Hook	15	216
11	03-Nov-21	Broken	Hook	35	1120
12	07-Feb-22	Broken	Hook	30	768
13	24-Oct-22	Broken	Hook	40	2072
14	10-Nov-22	Broken	Hook	80	136
15	13-Sep-23	Broken	Hook	60	2456

There were 15 failure events during the 2017–2024 period. Time to Failure values varied between 24 hours and 2648 hours, indicating instability in service life due to non-uniform operating conditions. Based on confirmation with maintenance staff, the very short service life was caused by a direct collision between the hook and punch, which generated high impact stress in the contact area. This sudden impact triggered extreme stress concentration on the hook surface, resulting in crack initiation and rapid fracture propagation without plastic deformation. This mechanism is consistent with the results of visual inspection which showed typical characteristics of brittle fracture, namely a relatively flat, sharply angled fracture surface that formed suddenly due to a momentary shock load. Similar failure patterns have been reported in industrial machinery where repeated misalignment leads to localized impact loading, significantly shortening component service life [15], [16].

3.3. Chemical Composition Test

After testing, the chemical composition of the hook material was obtained as shown in Table 2.

Table 2. Chemical composition of hook material.

Elements	Test Results (%)
C	0.599
Mn	1.000
P	0.023
S	< 0.0100

Based on these results, the base material of the broken hook can be classified as medium carbon steel because it has a carbon content between 0.30–0.60% [7]. One type of carbon steel that falls into the medium carbon category is AISI 1060. According to the ASM Handbook Volume 1 standard, the chemical composition of AISI 1060 is in the range of 0.55–0.65% C, 0.60–0.90% Mn, and 0.15–0.35% Si, with very low levels of other elements such as P and S [16].

The chemical composition test results showed that the hook material had a carbon content of 0.599% and a manganese content of 1.000%, indicating that the material is a medium carbon steel, type AISI 1060. The high carbon content increases the hardness and tensile strength of the steel, but reduces the material's ductility and toughness. Manganese slightly exceeding the standard also increases hardness, but at higher levels it can reduce shock resistance. Meanwhile, phosphorus and sulfur, even within safe limits, can potentially increase the material's brittleness. The combination of high carbon and manganese levels makes the steel hook hard but less ductile, so that when subjected to sudden impacts, the energy is not absorbed through plastic deformation but instead results in rapid brittle fracture, as seen in visual inspection. Previous studies confirm that increased carbon and manganese content enhances hardness but significantly reduces impact toughness, especially when insufficient tempering is applied [9], [18].

3.4. Hardness Test

The average hardness value of 22–23 HRC for both broken and fresh hooks indicates a hardness level typical of partially hardened medium carbon steel. This value indicates that the material is quite hard, but the impact energy is not absorbed through plastic deformation. When the hook experiences direct impact with a punch, the impact energy is not absorbed through plastic deformation, but instead causes a brittle fracture that propagates rapidly from the point of stress concentration. This finding confirms that the brittle nature of the material has a direct correlation with high hardness test results.

4. Conclusion

The failure mechanism of the hook component was identified as brittle fracture caused by impact stress exceeding the material’s strength. The fracture surfaces were flat and granular, showing no plastic deformation. The main cause was direct collision between the hook and punch, triggered by misalignment due to bearing wear. The hook material, classified as medium carbon steel with 0.599 wt.% C and 1.000 wt.% Mn, exhibited high hardness but insufficient toughness, making it prone to sudden fracture.

To improve component durability, it is recommended to apply surface hardening (such as flame hardening) followed by light tempering to balance hardness and ductility. Additionally, shot peening should be introduced to generate compressive residual stress, delaying crack initiation. Regular non-destructive inspections and alignment checks are essential to prevent impact-induced failures.

The main contribution of this study lies in the integration of visual fracture analysis, long-term maintenance data, and material characterization to identify brittle fracture as the dominant failure mechanism in hook components of automatic packaging machines. This approach provides a practical and systematic framework for failure diagnosis in industrial environments, where detailed numerical simulations are often unavailable.

However, this study is limited to visual inspection and basic mechanical testing. Future work should include detailed fractographic analysis using scanning electron microscopy (SEM), impact toughness testing, and finite element simulation to quantify stress distribution during impact events. These efforts will further enhance the understanding of crack initiation behavior and support the optimization of hook design and material treatment.

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