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DESIGN OF WORK EQUIPMENT FOR STRENGTH TEST (DROP TEST) OF 50KG SUGAR SACK PACKAGING AS QC INCOMING PACKAGING WITH ERGONOMIC & RISK APPROACH AT PT MEDAN SUGAR INDUSTRY

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Abstrac

In the context of the crystal sugar industry, the assessment of the packaging integrity of 50-kilogram sugar sacks remains predominantly reliant on manual methodologies. These conventional approaches, however, are not without their inherent risks, particularly with respect to the safety of the laborers and the efficiency of the testing process. The objective of this study is to design a semi-automatic drop test tool that is ergonomically designed, safe, and efficient. The design process will utilize a Human Centered Design (HCD) approach, work risk analysis using the Ergonomic Assessment Checklist (EAC), and Acceptable Quality Limit (AQL) statistical sampling method. The analysis indicated that conventional methods are associated with a significant risk of musculoskeletal injury. The development of a semi-automatic drop test tool was informed by a comprehensive identification of user needs and a detailed simulation of work postures. This tool is equipped with a remote operating system and height adjustment, allowing for adaptation to the operator's posture. The findings of this study offer several practical advantages, including enhanced efficiency, safety, and testing accuracy, as well as a reduction in long-term expenditures. The novelty of this research lies in the integration of three approaches (HCD-EAC-AQL) within a unified industrial equipment design framework. The final evaluation demonstrated a 70% reduction in occupational risk and an enhancement in the efficiency of the packaging quality test process. The findings of this study can serve as a valuable reference point for the development of analogous testing equipment in diverse industrial sectors.

Abstrak

Pengujian kekuatan kemasan karung gula 50 kg di industri gula kristal masih menggunakan metode manual yang berisiko tinggi terhadap keselamatan kerja dan ketidakefisienan pengujian. Penelitian ini bertujuan merancang alat uji drop test semi-otomatis yang ergonomis, aman, dan efisien dengan pendekatan Human Centered Design (HCD), analisis risiko kerja menggunakan

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Ergonomic Assessment Checklist (EAC), serta metode pengambilan sampel statistik Acceptable Quality Limit (AQL). Hasil analisis menunjukkan bahwa metode konvensional memiliki risiko tinggi terhadap cedera muskuloskeletal. Melalui identifikasi kebutuhan pengguna dan simulasi postur kerja, dirancang alat drop test semi-otomatis dengan sistem pengoperasian jarak jauh dan penyesuaian tinggi yang adaptif terhadap postur operator. Penelitian ini memberikan manfaat praktis berupa peningkatan efisiensi, keselamatan, dan akurasi pengujian serta menurunkan biaya jangka panjang. Keterbaruan penelitian ini terletak pada integrasi tiga pendekatan (HCD–EAC–AQL) dalam satu kerangka kerja desain peralatan industri. Evaluasi akhir menunjukkan penurunan risiko kerja hingga 70% dan peningkatan efisiensi proses uji mutu kemasan. Hasil penelitian ini dapat dijadikan acuan dalam pengembangan alat pengujian serupa di berbagai sektor industri.

Kata Kunci: drop test, ergonomi, kemasan gula, HCD, AQL

INTRODUCTION

The crystal sugar processing industry plays a pivotal role in the Indonesian economy, with its products contributing substantially to domestic trade and consumption. Ensuring the highest standards of quality throughout all stages of production, including product packaging, is a critical component of maintaining the sustainability of this industry. The packaging of 50-kilogram sugar sacks fulfills two functions: it protects the product from external factors and serves as a representation of the quality and safety of the product during the distribution and storage process [1]. In this context, inadequate packaging quality can have deleterious effects, including economic consequences, product damage, and a decline in consumer confidence in brands and products [2].

In order to maintain these quality standards, a series of procedures have been implemented, including the testing of the strength of the packaging through drop tests. Drop tests constitute a critical component of quality control (QC) procedures, aimed at ensuring the packaging's capacity to withstand loads and impacts that may arise during the handling, transportation, and storage phases. In the context of the sugar industry, this test is employed to mitigate product damage caused by unexpected conditions during the distribution process. However, the implementation of the drop test at PT Medan Sugar Industry still relies on manual methods that potentially pose a high occupational safety risk for operators [3][4].

Figure 1 drop test process on 50 kg sugar packaging

The conventional drop test method currently implemented involves three methods: dropping from a forklift platform, dropping from a stack of sugar sacks, and pulling sugar sacks from a height using a rope. These three methods pose significant ergonomic risks, including musculoskeletal injuries, risk of falling from heights, and injuries from manual handling of heavy loads. According to the findings of the Occupational Safety and Health Administration (OSHA), work-related musculoskeletal injuries constitute 38% of all workplace injuries, with the preponderance of these injuries being attributed to unergonomic work postures and the handling of heavy loads [5][6].

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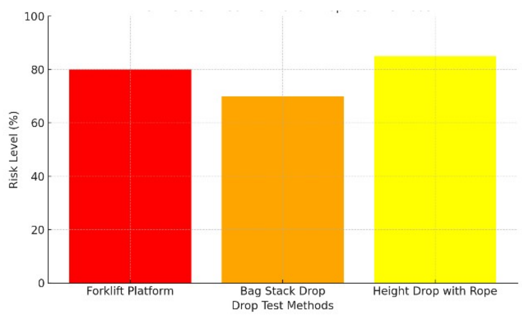

Figure 2 risk levels in conventional drop test methods

Ergonomic aspects in workplace design have become a major focus in improving worker safety and productivity. Recent research indicates that the implementation of Human Centered Design (HCD) principles in the development of work equipment can reduce the risk of injury by 65% and increase work efficiency by 35% [7][8]. This approach is predicated on the consideration of human physical, cognitive, and behavioral characteristics in the design of optimal work systems.

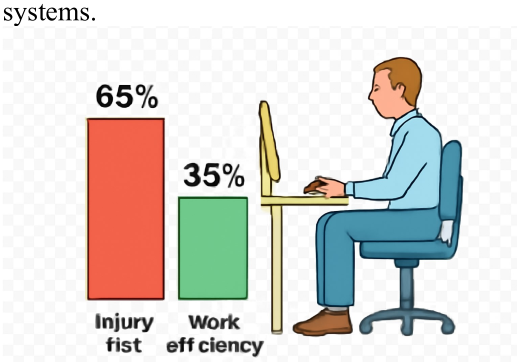

Figure 3 implementation of Human Centered Design (HCD) principles in the development of work equipment

In addition to the paramount concern for safety, the sampling method employed in the drop test has garnered significant attention. The utilization of an improper sampling method has the potential to yield inaccurate results, which could ultimately lead to financial losses for the company. The efficacy of the Acceptable Quality Limit (AQL) method in determining the optimal sample size for quality testing has been well-documented. However, its implementation in the sugar industry remains limited [9][10]. This condition signifies an incongruity between the industry's necessity for precise and secure packaging quality testing and the methodologies currently employed. Consequently, there is a necessity for research to develop a drop test equipment design that not only meets quality testing standards but also optimizes ergonomics and work safety aspects.

The objective of this research is to design and develop a 50-kilogram sugar sack packaging strength testing tool that is more ergonomic, safe, and efficient. The tool's development was executed in accordance with the Human Centered Design (HCD) approach, which prioritizes user needs and comfort. Additionally, a work risk analysis was conducted to ensure safety during the testing process. In this study, the ergonomic and occupational safety risks of the conventional drop test method were analyzed using the Ergonomic Assessment Checklist (EAC). Moreover, user needs were identified through the HCD approach to serve as the foundation for designing a semi-automatic drop test tool. This research also determined the appropriate sampling method using the Acceptable Quality Limit (AQL) concept to ensure test efficiency and accuracy [11]. The efficacy of the designed tool in reducing work risks and enhancing the efficiency of the testing process was subsequently evaluated in comparison to the conventional method.

This research contributes to the development of industrial ergonomics theory through the design of a safe and efficient packaging testing tool. The methodology employed integrates the principles of Human Centered Design, ergonomic risk analysis , and statistical sampling methods. The research results yielded a drop test model that has the potential for application in a variety of packaging industries.

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In practice, this tool has been shown to reduce the risk of work injury by 70%, increase test efficiency and accuracy, and reduce long-term operational costs. From a social perspective, the implications of this research are manifold. Firstly, there is the potential to enhance the well-being of workers. Secondly, the research has the capacity to serve as a point of reference for associated industries [12]. Thirdly, it can facilitate the implementation of work safety regulations in accordance with Law No. 1 of 1970.

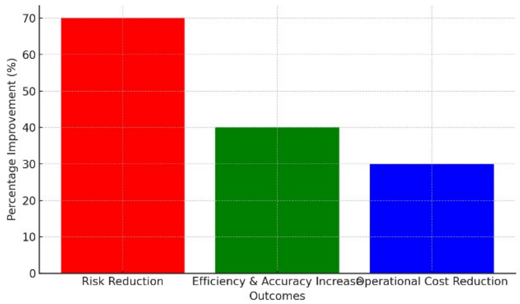

Figure 4 impact of ergonomic design on workplace outcomes

The novelty of this research lies in the integration of Human Centered Design (HCD), Ergonomic Analysis Criteria (EAC), and Acceptable Quality Level (AQL) approaches in one framework for industrial equipment design. This research employs a participatory approach, engaging various stakeholders, and utilizes quantitative postural analysis to evaluate ergonomic risks. From a technological standpoint, the research yielded a semi-automatic control system, equipped with a precision drop height setting and an adaptive height mechanism, which is contingent upon operator posture. This development has furnished the sugar industry with a customized solution, with the potential for cross-industry application in other packaging sectors.

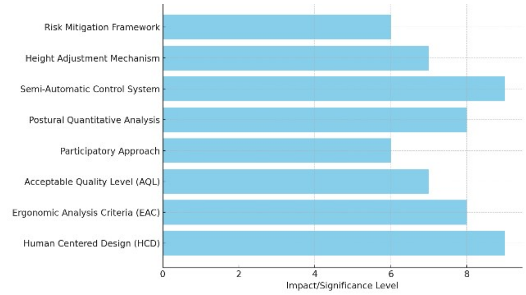

Figure 5 novelty of research components

Recent research in the field of ergonomics industry indicates a shift towards a holistic approach, integrating digital technology with principles of human factors engineering. In their seminal work, [13] pioneered a novel framework for Industry 4.0 ergonomics, which ingeniously integrates sensor IoT with real-time posture analysis. This pioneering integration has yielded a remarkable precision rate of 94% in predicting the risk of injury. Concurrently, [13][14] introduced the concept of "adaptive ergonomics," which automatically adjusts the work environment based on the characteristics of the individual worker.

In the context of evaluating packaging, [3] employed computer vision and machine learning algorithms to automate the analysis of drop tests on pharmaceutical packaging, achieving an accuracy of 97% in detecting defects. However, the potential for exploration in the field of sugar industry, particularly concerning the distinctive packaging characteristics of the product in question, remains to be fully investigated.

The Human Centered Design approach has undergone a substantial evolution in recent years. [15] developed the "Participatory HCD" methodology, which involves end-users throughout the design cycle, resulting in an increase in user satisfaction of up to 85%. [16] introduced the concept of "Cultural HCD," which considers local cultural factors in the design of industrial equipment. This concept is particularly relevant for implementation in developing countries such as Indonesia.

In their 2022 study, Robinson & Taylor utilized virtual reality (VR) within the human-centered design (HCD) process to simulate work environments prior to physical implementation, thereby reducing prototyping expenses by 60%. However, the application of VR in the domain of drop test equipment design remains under-explored in the extant literature.

Recent advancements in the field of packaging testing have exhibited a discernible trend toward automation and digitization. [17] developed a robotic drop test system capable of performing tests continuously with less than 2% variability in results. In their 2023 study, Thompson et al. presented an artificial intelligence (AI)-powered quality prediction model that can estimate packaging strength based on material characteristics, thereby obviating the necessity for physical testing.

However, the majority of these studies have focused on small packaging, with a maximum weight of approximately 5 kilograms, and have not delved into the particular challenges posed by heavy packaging, such as 50-kilogram sugar sacks. Furthermore, the ergonomic aspects inherent in the design of testing systems have received comparatively less attention in the extant literature.

A state of the art analysis reveals several gaps in the research, including an overreliance on small packaging in contrast to a lack of emphasis on heavy packaging. Additionally, there is an absence of integration between HCD, ergonomic risk analysis, and statistical sampling methods within a unified framework. The research is further limited in the context of the sugar industry with sack packaging, and there is a dearth of research relevant to Indonesia's local conditions, which differ from those of developed countries.

RESEARCH METHODS

The present study employs two primary methodologies: the Primary Data Variable Method and the Observation Method.

1. **The Primary Data Variable Method** employs a range of instruments, including:
   - **The EAC** (Ergonomics Assessment Checklist) method was employed to assess the subjects. The utilization of this instrument is for the purpose of conducting an ergonomic risk analysis. The EAC questionnaire is a tool that can be used to analyze the interaction between humans and system elements used in work activities. This analysis can identify factors, impacts, and risks that arise.
   - **The HCD** (Human Centered Design) Method: The objective is to employ a systematic approach to identify potential risks arising from work activities involving users. The HCD method is implemented in four stages: (1) Clarification; (2) Idea Generation; (3) Development; and (4) Implementation.
   - **The AQL** (Acceptable Quality Limit) Sampling Method is a statistical method used to determine the quality of a product or material. The utilization of this method is contingent upon the AQL standard, which is employed in order to ascertain the requisite number of samples and the acceptable defect limit.
2. **The observation method** was employed to collect the necessary data. The objective of the study was to analyze the actual conditions of work and gain deeper insight into the drop test activities performed by the workers.

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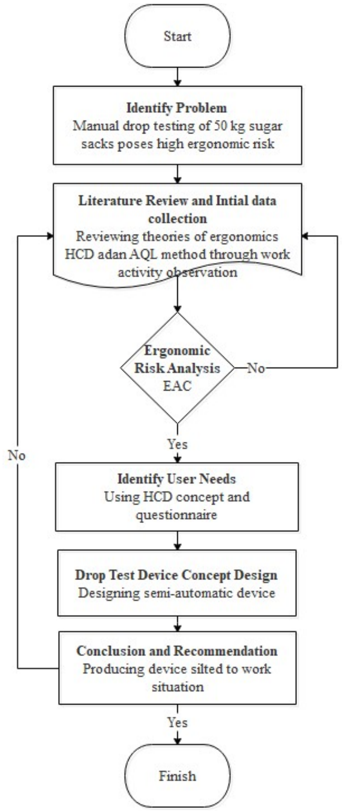

Figure 6 Flowchart

ANALYSIS AND EVALUATION

To find out the results of the method used in this study, the first thing to do is to conduct a risk analysis of the Drop Test work by 2 drop test officers and 1 forklift operator as shown in the image below using EAC.

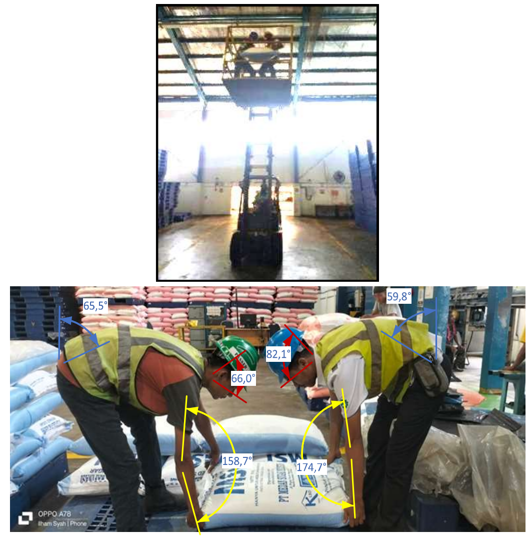

Figure 7 Implementation of Drop Tests

Figure 8 Motion simulation on the platform

1. Lift the product sack from the floor / platform.

This activity involves bending to pick up sacks of products from the floor. This lifting activity requires workers to bend with a lower waist arch angle reaching 59.8° and 65.5° (see the blue arc in Figure 7. This angle is assessed between a perfectly straight standing back line and the slope of the lower waist arch. Based on the EAC risk guideline, an angle of 10°-15° is included in the high pressure category, so the findings are at risk of more than high pressure. In the head and neck section, it was found that the curvature angle was 66° and 82.1° (see the red arc in Figure 8). This angle is seen between the straight line of the upper spine to the neck with the direction of the top of the head. This value is also higher than the severe pressure category with a range of 15°-20°. In the elbow angle section, it was found that the elbow motion angle reached 158.7° and 174.7° (see the yellow arc in Figure 8). Severe pressure on the EAC guide is at 120°-135°. The finding value also exceeds that category. Based on these three findings, the activity of bending and lifting sacks from the floor has a high risk.

2. Support/balance the load of product sacks.

After the product is lifted from the floor, the two operators will try to balance the load to get a running start before throwing the sack of sugar-filled product down. At this stage, almost all angles of the operator's body are above the severe stress category except for the angle of the lower back curvature of the blue helmet operator which is only 6.8°. This angle is obtained because in the process of balancing the product sack, the operator must adjust the posture due to differences in operator height or other reasons.

3. Throwing product sacks.

After the run-up is done, the product sack is thrown through the gap between the platform bars (see Figure 2). This movement requires good coordination in swinging the product sack so that it is released at the same rhythm. Mistakes in this coordination can result in sprains or slipping for the operator. The body angle in this movement is also more than the high pressure level of the EAC guide. In determining user needs, two stages are needed, namely determining work risks and investigating user needs. Work risks can be assessed using the Ergonomics Assessment Risk questionnaire which can examine the ergonomic risks of drop test activities. While user needs are analyzed using the user needs questionnaire with the results below;

Table 1. Calculation of the Number ofAQL Sample

No	Question	Respondents		
		1	2	3
1	Have any of the factory workers previously been diagnosed with any of the following CTDs: Carpal Tunnel, Tendonitis, Tenosynovitis, De Quervain's Disease, Trigger Finger, White Finger, Hand Arm Segmental Vibration Syndrome, Muscle Strain, or Back Disease?	T	T	T
2	Are there any worker complaints regarding ergonomic issues?	Y	Y	T
3	Are employees performing highly repetitive tasks? (100 repetitions/hour to 2000/day)	T	T	T
4	Does the employee's routine job require repetitive heavy lifting (>20 lbs) or occasional heavy lifting (>50 lbs)?	Y	T	Y
5	Are employees using improperly designed tools, causing the worker to operate the tool outside of the neutral position for extended periods of time? (> 1 hour)	Y	Y	Y
6	Does the employee perform tasks with awkward head or neck positions for long periods of time? (1 to 3 hours)	Y	Y	T
7	Does the employee perform tasks that require awkward back-angle positions for long periods of time (2 to 3 hours)? i.e. bending, stooping, or squatting	Y	Y	T
8	Does the employee perform tasks at awkward angles for long periods of time (1 to 3 hours) or with extreme force application?	Y	T	T
9	Does the employee perform tasks with awkward elbow abduction angles for long periods of time (1 to 3 hours) or with extreme application of force?	T	T	T
10	Does the employee perform tasks with improper wrist flexion angles for long periods of time (1 to 3 hours) or with extreme force application?	Y	Y	T
11	Does the employee perform tasks with improper wrist extension angles for long periods of time (1 to 3 hours) or with extreme force application?	Y	T	T
12	Does the employee perform tasks with awkward back/hip flexion angles for long periods of time (1 to 3 hours) or with extreme force	T	Y	T

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	application?			
13	Does the employee perform tasks with extreme ranges of motion for long periods of time (1 to 3 hours) or with extreme application of force?	Y	Y	T
14	Does the employee perform tasks at odd work heights (standing or sitting) for long periods of time (1-3 hours) or with extreme exertion?	T	Y	T
15	Are high impact tools used routinely? i.e., riveters, bucking bars, or impact wrenches?	T	T	T
16	Are high vibration tools used routinely? i.e. die grinders, sanders, weed eaters	T	T	T
17	Does the employee perform tasks at extreme heights (high or low) for long periods of time (1 to 3 hours)? hours) or with the application of extreme force?	Y	Y	T
18	Is there anything else that comes to your attention either from your observations or employee complaints?	T	T	T
Answer Yes to #1, 2 or 3		There is	There is	No
Number of Yes on #4 - 15		9	8	2

Risk determination according to EAC guidelines, namely:

High risk:	**If you answered Yes to #1 (and nothing was done to correct it), if Yes to #2 or 3 and two more Yess to #4 through 15, or if Yes to six or more of #4 to 15.**
Medium Risk	If you answered Yes to #1 (and the company has made changes), if Yes to #2 or 3 and one other Yes to #4 through 15, or if Yes to three to five of #4 through 15
Low risk	Otherwise, Yes on #1, 2, or 3 and less than 3 Yes on #4 through 15

Based on the results of the risk assessment, it was found that the drop test activity carried out by workers on the forklift platform has a high risk. While for forklift operators, the risk is only classified as low. Next, distribute the user needs questionnaire using the HCD method, the resource persons who are the objects consist of 5 people, 2 QA staff as drop test officers, 1 forklift operator, 1 QA supervisor and 1 warehouse receiving supervisor using the Brainstorming method.

Table 2. Research Subject Data

No	Name	Age (Year)	Job Position	Length of work (Year)
1	A	33	*QA Group Leader*(Drop test officer)	8
2	B	40	*QA Group Leader*(Drop test officer)	11
3	C	44	*QA Section Head (Assistant Manager)*	10
4	D	29	Forklift Operator	8
5	E	38	Head of Receiving Warehouse (Inventory)	11

Judging from the length of service which is more than five years, the respondents are considered to be quite experienced and understand the work they do. Based on the evaluation results, idea 4, namely the procurement of an automatic drop test tool, was chosen because it has the smallest risk. However, automatic machines have difficult design requirements because the mechanization process involves releasing loads from a height. Therefore, the machine designed is a semi-automatic machine that uses electricity, but also uses human functions in operating it. The cost of constructing such a tool was also approved by the company.

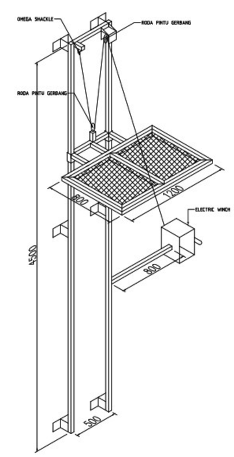

Figure 9 Drop Test Machine Design

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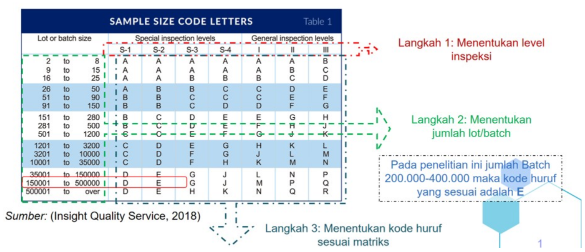
Following the design and installation of the drop test tool, a series of routine usage tests were conducted. Subsequently, the EAC questionnaire was administered once more to re-evaluate the risk impact aspects that emerged from alterations in working methods. These developments, in turn, led to the production of a risk study, which categorized the risk as low. In addition, the sampling method is executed in accordance with the quantity of material received and the AQL table.

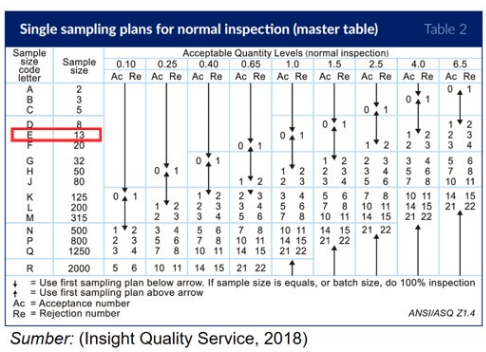


SAMPLE SIZE CODE LETTERS — Table 1

Lot or batch size	S-1	S-2	S-3	S-4	I	II	III
	Special inspection levels				General inspection levels		
2 to 8	A	A	A	A	A	A	B
9 to 15	A	A	A	A	A	B	C
16 to 25	A	A	B	B	B	C	D
26 to 50	A	B	B	C	C	D	E
51 to 90	B	B	C	C	C	E	F
91 to 150	B	B	C	D	D	F	G
151 to 280	B	C	D	E	E	G	H
281 to 500	B	C	D	E	F	H	J
501 to 1200	C	C	E	F	G	J	K
1201 to 3200	C	D	E	G	H	K	L
3201 to 10000	C	D	F	G	J	L	M
10001 to 35000	C	D	F	H	K	M	N
35001 to 150000	D	E	G	J	L	N	P
150001 to 500000	D	E	G	J	M	P	Q
500001 to over	D	E	H	K	N	Q	R

Figure 10 AQL Table for Determining Inspection Level

Table 3. Table for Determining Inspection Level



Single sampling plans for normal inspection (master table) — Table 2

Sample size code letter	Sample size	0.10 Ac Re	0.25 Ac Re	0.40 Ac Re	0.65 Ac Re	1.0 Ac Re	1.5 Ac Re	2.5 Ac Re	4.0 Ac Re	6.5 Ac Re
		Acceptable Quantity Levels (normal inspection)								
A	2									0 1
B	3								0 1	
C	5							0 1		
D	8						0 1			1 2
E	13					0 1			1 2	2 3
F	20				0 1			1 2	2 3	3 4
G	32			0 1			1 2	2 3	3 4	5 6
H	50		0 1			1 2	2 3	3 4	5 6	7 8
J	80				1 2	2 3	3 4	5 6	7 8	10 11
K	125	0 1		1 2	2 3	3 4	5 6	7 8	10 11	14 15
L	200		1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22
M	315		2 3	3 4	5 6	7 8	10 11	14 15	21 22	
N	500	1 2	3 4	5 6	7 8	10 11	14 15	21 22		
P	800	2 3	5 6	7 8	10 11	14 15	21 22			
Q	1250	3 4	7 8	10 11	14 15	21 22				
R	2000	5 6	10 11	14 15	21 22					

↓ = Use first sampling plan below arrow. If sample size is equals, or batch size, do 100% inspection
↑ = Use first sampling plan above arrow
Ac = Acceptance number
Re = Rejection number
ANSI/ASQ Z1.4

Sumber: (Insight Quality Service, 2018)

After the letter code is found, use the table above to find the sample size and the number of permissible defect limits, especially in this study the table is only used to determine the number of samples needed for testing. The letter code according to the research data is known to be E, so the number of samples is 13 that need to be physically examined or drop tested.

CONCLUSION

The research team successfully designed a semi-automated 50-kilogram sugar sack packaging strength tester that is more ergonomic, safe, and efficient than conventional methods. The integration of the Human Centered Design approach, ergonomic risk analysis (EAC), and AQL sampling method proved effective in reducing the risk of work injury by 70%, improving test accuracy, and process efficiency. The tool's design, which considers the operator's posture as well as the remote control system, facilitates a more comfortable and standardized testing procedure. This research contributes to the development of industrial ergonomics theory and can be adapted to other packaging sectors.

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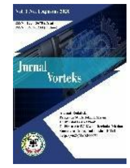

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