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Quality Analysis of 5.56 mm Ammunition Defect using Taguchi Method: A Review

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In a manufacturing company, the quality loss is estimated by considering the number of defects. Taguchi is a method that finds strong conditions in uncontrollable environments of the field. Taguchi quantifies quality loss through a quality loss function. The Taguchi method particularly is focused on industrial processes. The method is actualizing quality philosophy for continuous quality improvement and cost reduction to improve manufacturing performance. The analysis is designed using Taguchi technique which is related to quality. A high-quality product has a minimal defect. The Taguchi method is used to analyze several defects of ammunition to reduce the number of ammunition defects. Ammunition consists of several parts are called projectile or bullet, cartridge case, propellant charge, and primer. Every part of its process possibly contributes to any defect. The defect type in every part of ammunition consists of critical, major, and minor defects. This paper is focused on cartridge case caliber 5.56 mm defect by using the Taguchi method. The quality characteristic of the experiment result used is smaller the better. Critical to Quality (CTQ) is determined to get a critical defect for cartridge cases such as split and perforated case. The influencing factors are brass cup thickness, hardness case after annealing, and annealing temperature. The Taguchi method is effective in reducing defects for the ammunition process to produce a good quality product.

Keywords: *Taguchi method; quality; defect; ammunition*

1. INTRODUCTION

In the military department, the defense is connected with military activities and products, such as artillery training in shooting ranges and ammunitions [1]. Guns and ammunition industry is a company which is specialized in the retail of guns and ammunition. Each production is prioritized to supply national defense and security equipment needs and is aimed to fulfill requirements from other parties. Primary customers are government security organizations and private security vendors. The annual demand for ammunition and weapons is showing an increasing trend graph for total arms sales of companies in the Stockholm International Peace Research Institute (SIPRI) from 2002 to 2017 [2] (**Figure 1**).

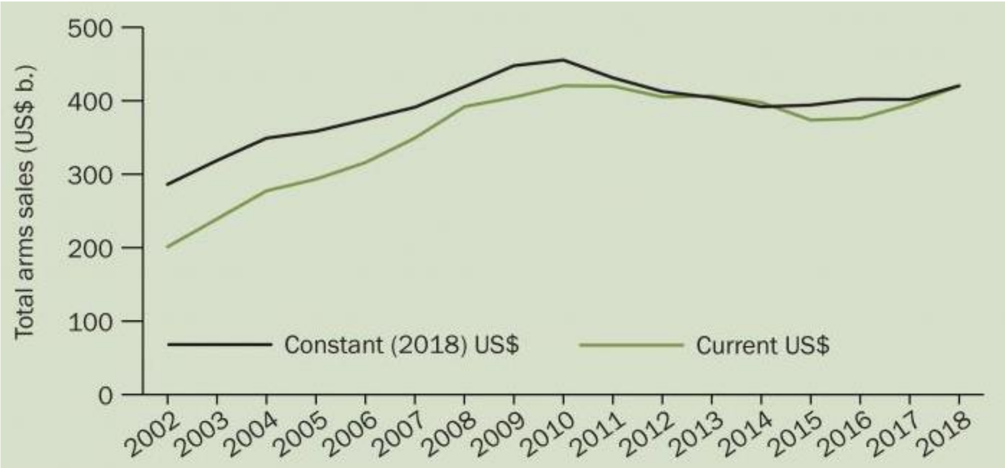

Figure 1: Trend graph for total arms sales in the SIPRI [2]

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Ammunition is the collective term for all projectiles which are thrown, slung, or fired by energy stored and released by triggering process [3]. Ammunition consists of a projectile, cartridge, propellant charge, and primer. The compositions of ammunition are metals including lead, chromium, nickel, zinc, and copper. Propellant igniter or primer contains metals such as Lead, Barium, and Antimony compounds. A double base propellant contains Barium/ Kalium salts as a flash suppressant [4].

The propellant is chemical compositions used to hurl projectiles containing a warhead towards target [3]. Two types of propellants are called guns and rocket propellant. Gun propellant is classified into smokeless powder and black powder. The smokeless powder consists of single-base propellant (nitrocellulose propellant), double base propellant (nitrocellulose and nitroglycerine propellant), triple base propellant (nitrocellulose, nitroglycerine, and nitroguanidine propellant) [5]. Rocket propellants, divided according to its phase, are liquid propellants and solid propellants. Ammunition consists of fixed, separable, and separate loaded ammunition [6].

Fixed ammunition consists of a container for the propellant charge, called cartridge case [6]. It is used in a tank, anti-aircraft, aircraft weapons, and most small arms [3,7]. Separable ammunition or semifixed ammunition consists of cartridge case and projectile. However, the case is not firmly attached to the projectile and can be removed in the field to adjust the charge. It is used in older howitzers and still used in shotguns. Separate-loaded ammunition or separated ammunition consists of a projectile, which is loaded first into the weapon, propellant charge loaded next, primer and igniter loaded last. It is used in howitzers, large naval guns, and mortars. Mortars ammunition is used for calibers between 40-120 mm. The Manufacturing process of ammunition particularly cartridge case will be discussed below.

1.1 Manufacturing steps of ammunition

The cartridge cases for the centerfire case starts from brass strip [7]. The process is as follows:

1. Blanking and cup
   The first operation is forming a cup from strip through the blanking process.
2. Annealing, pickling, and washing
   The brass cups are annealed before the first drawing process. The cups are rinsed to remove the lubricant and are then put into annealing furnace. After annealing, the cups are rinsed with acid solvent to remove oxide. The cups are then soaped, rinsed, and dried.
3. Drawing
   There are three steps of the drawing process. Each step only differs in punches and dies size. An annealing process is done between each drawing process.
4. Bunting, pocketing, and heading
   These three operations are usually carried out on the same machine. The cartridge case is undergoing flash hole piercing and length trimming operations after heading.
5. Body annealing
   Body annealing is used to soften the case before the tapering and necking process. Cartridge cases are annealed for just a moment.
6. Reducing
   The body is tapered, the shoulder and neck are formed, and the neck is sized to the final inside dimension. After reducing, the case goes to pickling and washing, flash hole piercing, or head-turning.
7. Piercing
   Piercing is done on the press machine. The flash holes are drilled or punched with Berdan or Boxer typesetting.
8. Head-turning and length trimming
   Head-turning is a process for making the groove or extractor. The length of the case is trimmed to the final dimension in this process also.
9. Mouth annealing
   The function of mouth annealing is to prevent crack. Particularly the bottlenecked case has to be mouth annealed.
10. Primer seating
    The primer is seated and crimped into the base of the cartridge case.
11. Mouth waterproofing
    Military rifle cartridge is protected against oil or water by having the case inner mouth coated with a thin layer of asphaltic material.

1.2 Taguchi Method

The Taguchi method is a method that finds strong conditions in uncontrollable environments of the field [8]. The Taguchi method particularly focuses on industrial processes [9]. The method is actualizing quality philosophy for continuous quality improvement and cost reduction to improve manufacturing performance [10,11]. The analysis is designed using Taguchi method which is connected with quality. The Taguchi method has become useful for obtaining high-reliability results in researches, particularly since it saves a great deal of time and cost of materials [12,13]. A high-quality product has a minimal loss to society [14] which can be due to failure, repair, variation in performance, pollution, noise, etc. The types of loss are product returns, warranty costs, customer complaints and dissatisfaction, time and money spent by the customer, eventual loss of market share and growth.

2. AVAILABLE TECHNOLOGY

The ammunition company treats all customer complaints as extensions of its inspection [7]. Most customer complaints about product defects or failures. The most defective or failed product is due to the manufacturing process. Various defects and malfunctions during the manufacturing process can occur with ammunition. Several types of defects occur in ammunition during the manufacturing process e.g. misfire (cartridge fails to fire under the firing pin blow). It can be caused by no priming, no flash hole, improperly assembled primer, no powder, improperly seated primer. Two most serious ammunition defects are high pressure and burst cartridge case at one end, low pressures, and squibs at the other.

A squib is a cartridge that failed to reach its normal pressure range [7] which can be caused by very light powder and priming charge, incorrect powder, a very weak crimp in a shotshell, and a small bullet diameter in rimfire ammunition. Of all rimfire casualties is a burst case head which may be caused by high pressure, heading defect, thin, soft brass, headspace, sharp chamber mouth, lack of head support. As with rimfire, failure of the centerfire cartridge heads to withstand pressure is a serious matter since centerfire cases pressures are higher than working pressure. This can be solved by adjusting case dimensions and base metal thickness to obtain sufficient cold work during the pocketing and heading process to achieve the required hardness. Centerfire cases will tend to split if the wall thickness on one side of the case is greater than the opposite side. A deep scratch has the effect of weakening the case, due to a change in thickness and a concentration of stress (**Figure 2**).

Figure 2: Centerfire case failures caused by manufacturing faults [7]

Table 1: Defects of 5.56 mm military ammunition [7]

Critical 0% Allowed	Major AQL 0,25% defects allowed	Minor AQL 1,5% defects allowed
Split case	Stained, etched case	Stained
Perforated case	Roundhead	Scratch
No primer	Mouth not crimped in the cannelure	Wrinkle or fold
Cocked primer	No mouth anneal	No headstamp

The military standard provides procedures for determining and evaluating defects in small arms ammunition [15]. For small arms caliber 5.56 mm, the defects classification is described in military specification calibers 5.56 mm (MIL-C-9963F) [16]. Defects are classified as critical, major or minor [7]. A critical defect is one that could cause serious injury or worse to personnel. A major defect is a defect which could cause a failure to function. A minor defect is one which causes a general loss of effectiveness but does not cause a specific malfunction. The visual and gauging defects of caliber 5.56 mm ammunition are listed as follows (**Table 1**). Quality control for the defense industry is needed to control ammunition to obtain good quality ammunition. Cartridge case defects are including discolored, dirty, oily, round head, dent (**Figure 3**), split, perforated case (**Figure 4**), and scratch. Bullet defects are including dent (bullet), scratch (bullet), split bullet jacket, loose bullet, missing cannelure. Primer defects are including no primer, inverted primer, loose primer, dented, no waterproofing (primer pocket joint), and defective crimp. The military standard has a classification of defect that is used for the defense industry.

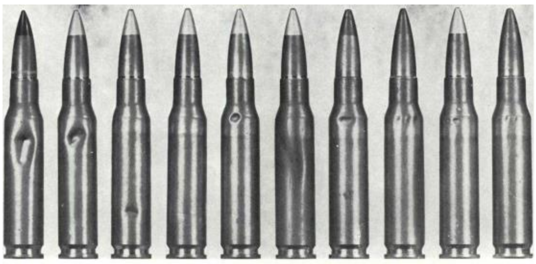

Figure 3: Dent case [15]

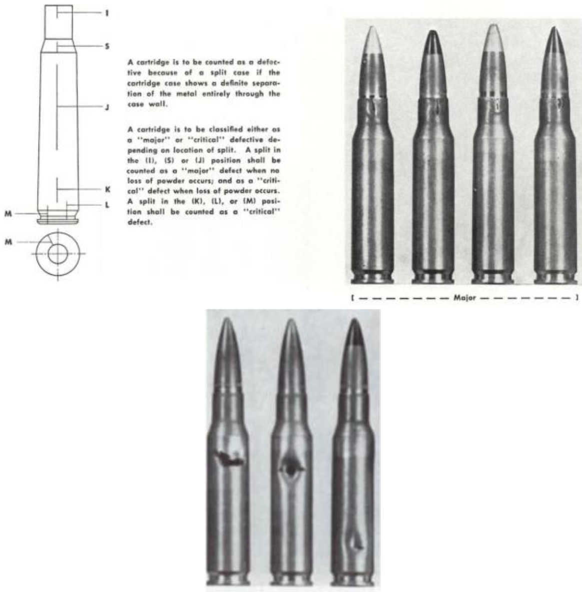

Figure 4: Split case (above); Perforated case (below) [15]

Two kinds of quality control for ammunition are quality control for commercial ammunition and quality control for military ammunition [7]. Quality control is a state of mind and attitude that starts with management and extends down to every individual in the organization. A few bad rounds can spoil the value of million rounds of ammunition as well as a company's reputation. A proper attitude of quality has to start with the highest level of management. Quality control for commercial ammunition is described in process sheets that specify of raw material physical characteristics, tools, gauges, physical checks, control limit for the chart, part dimension, machined to be used, and all tests to be made.

The quality control personnel work in setting up the control charts, then keeping the chart, and informing the operator if the process is approaching limits of control [7]. Quality control is not only for incoming material but also for in-process inspection and final inspection. Quality control is also responsible to ensure that the gauges on the job are properly calibrated. The inspection schedule for measuring a gauge must be strictly and discipline followed. All tools, dies, and punches are inspected by quality control before they can be used. Changes of tools in the production area are not permitted unless approved by the quality control and engineering.

Incoming material is inspected according to the specification defined by quality control before it can be used in the production process [7]. The inspection process on the machine is worked out by the quality control inspector, e.g. checking the part of ammunition e.g. cartridge case, bullet, and primer. Each part coming off the machine goes into a catch basket and stays at the machine, if it is good, then go to the next operation. Whenever a tool is changed, the first piece of the product must be inspected by quality control to ensure that the machine is ready to start. Quality control for final inspection is checking the final product of ammunition and ensuring that the ammunition works well. All these activities are routine or should be in any repetitive process in metalworking. Ammunition production requires a process that is capable of producing good ammunition and maintaining its quality to always be within normal limits with a continuous inspection.

Meanwhile, quality control for military ammunition is controlling a product during manufacture in the same way as commercial ammunition [7]. However, acceptance by the military is a different procedure compared to commercial products. In a military method, formal sampling, the test of the sample, and acceptance or rejection of the ammunition are worked out by using lot systems. The standard of military acceptance is using the US military specification for ammunition acceptance called “MIL-STD-105D”. The sample size is described by the lot size, as the general inspection level. The inspection may be normal, tightened, or reduced depending on the quality level of preceding lots submitted. The acceptable quality level (AQL) is used in quality control for military ammunition [16]. If the number of defects found in the sample is less than the acceptable number, the lot is accepted. If more defects are found than the smaller number, the lot is rejected. Quality analysis and quality improvement are eternal pursuits for manufacturing companies [17].

3. FUTURE OPPORTUNITIES

In the manufacturing industry, engineers strive to prevent an increase of non-conforming fraction [18]. Quality assurance implicates a special challenge [19]. To improve quality and reduce changeovers, a batch operation is typically introduced to reduce frequent product changes in many flexible manufacturing systems [20]. Quality is developing an optimal lot-sizing model with production and inspection quality investment, incorporating all the quality costs [21,22]. Quality assurance ensures that all policies, including methods, procedures, and technique sampling are being obeyed [16]. Sampling in military quality control (case study at PT. Pindad) is using a lot by lot with ANSI Quality Standard and Acceptable Quality Level (AQL). In Pindad, the major AQL sampling technique shall be 0.25 percent and the minor AQL case shall be 1.50 percent. The inspection procedure is using General Inspection Level II, double sampling and normal. Inspection is conducted due to final inspection or incoming inspection, some of the defect criteria are allowed, while the other defect cannot be allowed so one lot of production must be rejected if such defect occurred.

The lot size of each inspection differs e.g. in the final accuracy test, one lot of cal. 5.56 mm ammunition production is 201.600 pcs. 90 pcs of ammunition are taken from each lot for accuracy test sampling. If 3 pcs of ammunition are found with bad accuracy, the lot shall be accepted. If 5 pcs of ammunition are found with bad accuracy, the lot shall be rejected. If 4 pcs of ammunition are found with bad accuracy, a double sampling is needed. The brass cup is incoming material the cartridge and bullet. If there are 10.000 kg brass cup, 500 pcs should be taken as the sample. If 5 pcs brass cup are found with critical dimension defect, 10.000 kg brass cup shall be accepted. If 6 pcs brass cup are found with critical dimension defect, 10.000 kg brass cup shall be rejected. At the beginning of regular production, a sample shall be submitted with contract requirements [16].

The sample must be made by using the same materials, processes and procedures, and equipment as it will be used in regular production. After inspection and provisional acceptance, the sample shall be inspected for all requirements of the drawings and specifications specified in the contract. One hundred percent inspection shall be performed for all critical defects. Inspection for major and minor defects shall be performed by the classification of defects, using applicable sampling plans and acceptance criteria of MIL-STD-105 [16]. In Taguchi experiment there are three types of targets quality [14]:

1. *Nominal–the best*. The nominal value is the target. Achievement value close to zero, the quality is better.
2. *Smaller–the better*: It is a non-negative measurable characteristic having an ideal target as zero. Achievement the value is zero, quality is better.
3. *Larger–the better:* It is also a non-negative measurable characteristic that has an ideal target as infinity. Achievement infinite value, quality the better result

3.1 Determine Quality Characteristics

Determine quality characteristics of experiment results is using *smaller the better*. Lower defect occurred in cartridge case is better, so that will produce optimal level settings. Critical to Quality (CTQ) is a key characteristic that can cause a defect in the cartridge case. CTQ in this study is based on a type of critical defect. According to military specification calibers 5.56 mm (MIL-C-9963F [15], a critical defect for cartridge case has two kinds of defects such as split case and perforated case. Not all split case is critical, but only in a certain part. Split in the K, L, or M is a critical defect since it can cause loss of powder occurs (**Figure 5**).

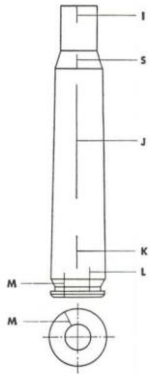

Figure 5: Critical part location of split cartridge case [15]

3.1.1 Determine the influencing factors

Determination of the influencing factors is obtained from the study of literature and observation. The influencing factor of cartridge case defect such as split and perforated case comes from material brass cup thickness, case hardness after annealing, and annealing temperature. If the wall thickness of the brass cup on one side is much greater or much less than the opposite side, a split defect can occur. The split defect occurred since the thicker side being stronger, stretch but little and the weaker side takes most of the strain. If the elastic limit of the brass is exceeded, it will split. The elastic limit is a variety of case hardness. If a case is too soft it will stretch too much. A deep scratch has the effect of weakening the case, due to a change in thickness and a concentration of stress. On rimfire another split, a crack across the rim is likely to occur, if the case is not carried out the relief annealing process after the heading process. The relief annealing is at a temperature of approximately 450-500 ^{0} F below the critical recrystallization temperature of brass. After analyzing the factors that will be used, then the next step is factor level determination for this experiment.

3.1.2 Implementation of Taguchi experiment

At the stage of conducting experiments, the Taguchi method will be made of a cartridge case sample consisting of controlled factors such as brass cup thickness, case hardness after annealing, and annealing temperature. The next step is inspecting the resulting cartridge case. The number of cartridge case defects is recorded based on two types of CTQ. If one or two CTQ type is found in a cartridge case then the cartridge case will be counted as a defect.

4. CONCLUSION

This paper discusses the quality improvement of cartridge case production better by applying the Taguchi method rather than the traditional method, particularly in the manufacturing industry. There are several types of defects in the ammunition component production process, e.g. cartridge case, bullet, and primer defect. Defect criteria are classified into three types, critical, major, and minor defect. This paper is focused on the caliber 5.56 cartridge case defect by using the Taguchi method. The quality characteristic of the experiment result is using smaller the better. Determine critical to quality (CTQ) to get critical defects for cartridge cases such as split and perforated case. The influencing factors are brass cup thickness, case hardness after annealing, and annealing temperature. The Taguchi method is effective in reducing defects for the ammunition process to produce a good quality product.

5. REFERENCES

[1] C. FERREIRA, J. RIBEIRO, S. ALMADA, T. ROTARIU, and F. FREIRE, "Reducing impacts from ammunitions: A comparative life-cycle assessment of four types of 9 mm ammunitions," *Sci. Total Environ.*, vol. 566–567, pp. 34–40, 2016.

[2] Stockholm International Peace Research Institute, SIPRI, https://www.sipri.org/research/armament-and-disarmament/arms-transfers-and-military-spending/arms-production. Accessed: October 2019.

[3] R. GERMERSHAUSEN, *Handbook On Weaponry*, First Engl. Dusseldorf: Rheinmetall GmbH, 1982.

[4] J. AURELL, A. L. HOLDER, B. K. GULLETT, K. MCNESBY, and J. P. WEINSTEIN,

"Characterization of M4 carbine rifle emissions with three ammunition types," *Environ. Pollut.*, vol. 254, p. 112982, 2019.

[5] I. G. CROUCH, G. APPLEBY-THOMAS, and P. J. HAZELL, "A study of the penetration behaviour of mild-steel-cored ammunition against boron carbide ceramic armors," *Int. J. Impact Eng.*, vol. 80, pp. 203–211, 2015.

[6] D. E. CARLUCCI and S. S. JACOBSON, *Ballistic Theory And Design on Guns And Ammunition*. London: CRC Press Taylor & Francis Group, LLC, 2018.

[7] E. G. FROST, *Ammunition Making*. Washington, DC: National RifleAssociation of America, 1990.

[8] S. REE, Y. H. PARK, and H. YOO, "A study on education quality using the Taguchi method," *Total Qual. Manag. Bus. Excell.*, vol. 25, no. 7–8, pp. 935–943, 2014.

[9] Y. I. TANSEL and S. YLDRM, "MOORA-based Taguchi optimization for improving product or process quality," *Int. J. Prod. Res.*, vol. 51, no. 11, pp. 3321–3341, 2013.

[10] P. GAMAGE, N. P. JAYAMAHA, and N. P. GRIGG, "Acceptance of Taguchi's Quality Philosophy and Practice by Lean practitioners in apparel manufacturing," *Total Qual. Manag. Bus. Excell.*, vol. 28, no. 11–12, pp. 1322–1338, 2017.

[11] I. ARIZONO, T. MIYAZAKI, AND Y. TAKEMOTO, "Variable sampling inspection plans with screening indexed by Taguchi's quality loss for optimizing average total inspection," *Int. J. Prod. Res.*, vol. 52, no. 2, pp. 405–418, 2014.

[12] T. CANEL, M. ZEREN, and T. SINMAZÇELIK, "Laser parameters optimization of surface treating of Al 6082-T6 with Taguchi method," *Opt. Laser Technol.*, vol. 120, no. June, p. 105714, 2019.

[13] G.S. PRAYOGO, and N. LUSI, "Determining the effect of machining parameters on material removal rate of AISI D2 tool steel in electrochemical machining process using the Taguchi method," *Proceeding of the international conference on mechanical engineering research and application ICOMERA*, Malang, Indonesia, p. 406-412, 2019.

[14] K. KRISHNAIAH and P. SHAHABUDEEN, *Applied Design of Experiments and Taguchi Methods*. New Delhi: PHI Learning Private Limited, 2012.

[15] A. CORPORATION ORDNANCE, *Military Standard Visual Inspection Standards For Small Arms Ammunition Through Caliber .50*, no. June. Washington, DC, 1958.

[16] A. MU, *Military Specification Cartridge 5.56 mm Ball M193*, no. October 1976. Washington, DC, 1970.

[17] Z. WEI, Y. FENG, Z. HONG, R. QU, and J. TAN, "Product quality improvement method in manufacturing process based on kernel optimization algorithm," *Int. J. Prod. Res.*, vol. 55, no. 19, pp. 5597–5608, 2017.

[18] J. E. CHIU and C. H. TSAI, "Monitoring high-quality processes with one-sided conditional cumulative counts of conforming chart," *J. Ind. Prod. Eng.*, vol. 32, no. 8, pp. 559–565, 2015.

[19] T. ARNDT, M. KUMAR, G. LANZA, and M. K. TIWARI, "Integrated approach for optimizing quality control in international manufacturing networks," *Prod. Plan. Control*, vol. 30, no. 2–3, pp. 225–238, 2019.

[20] J. WANG, J. LI, J. ARINEZ, and S. BILLER, "Quality bottleneck transitions in flexible manufacturing systems with batch productions," *IIE Trans. (Institute Ind. Eng.*, vol. 45, no. 2, pp. 190–205, 2013.

[21] S. H. YOO, D. KIM, and M. S. PARK, "Lot sizing and quality investment with quality cost analyses for imperfect production and inspection processes with commercial return," *Int. J. Prod. Econ.*, vol. 140, no. 2, pp. 922–933, 2012.

[22] Y. HE, C. GU, Z. HE, and J. CUI, "Reliability-oriented quality control approach for production process based on RQR chain," *Total Qual. Manag. Bus. Excell.*, vol. 29, no. 5–6, pp. 652–672, 2018.