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Study on Effects of Process Parameters on the Mechanical Properties of 40 mm L70 Cartridge Case

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Abstract:

The study investigates the effects of process parameters on the mechanical properties of the 40 × 365 mm L70 cartridge case used in HEI-T shells for anti-aircraft applications. The parameters examined include the ironing ratio during the deep drawing process, annealing temperature, and heat holding time during annealing. Experiments were conducted to evaluate the influence of each parameter throughout the manufacturing process. The Taguchi method was employed to identify the optimal conditions for maximizing the tensile strength and relative elongation of the material used in the cartridge case, while minimizing the number of experiments required.

Keywords:

cartridge case, process parameters, mechanical properties, Taguchi method, deep drawing

1 Introduction

The Bofors 40 mm L70 anti-aircraft gun is widely used in many countries around the world. Due to its widespread use, the weapon system is often modified to meet current requirements in the constantly evolving anti-aircraft artillery environment [1]. The 40 × 365 mm ammunition it uses includes various types of shells, such as:

- High-Explosive (HE) shells,
- High-Explosive Tracer (HE-T) shells,
- High-Explosive Incendiary Tracer (HEI-T) shells (commonly used in air defense missions),

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- Armor-Piercing Tracer (AP-T) shells,
- Training Practice Tracer (TP-T) rounds [2].

One of the critical components of the ammunition is the cartridge case, which is constructed from a copper alloy. It is a long hollow cylinder with a primer at the base and plays an essential role in maintaining the gun's continuous operation by ensuring reliable loading and firing [3, 4].

To ensure easy extraction of the cartridge case after firing, the clearance between the cartridge case wall and the chamber wall must have a certain value. This clearance depends on multiple factors, mainly on the elasticity of the cartridge case material, the relationship between stress and strain during firing, the diameter of the cartridge case at the location, the temperature of the powder gas, the initial clearance, and the time of extraction of the cartridge case. The design of the technological procedure for the production of cartridges must therefore be given great attention and studied from many standpoints [5]. The design of the 40×365 mm L70 cartridge case is based on theory and sample surveys. It ensures proper clearance between the cartridge case wall and the chamber wall. The mechanical properties of the material at key points must meet specific values, as shown in Tab. 1. The change in wall thickness affects the mechanical properties of the cartridge case. In particular, the required strength at 325 mm from the top is ranging from 540 to 660 MPa. To achieve the desired shape, dimensions, and mechanical properties of the cartridge case wall, a forming process must be combined with suitable heat treatment [6-8].

Tab. 1 Mechanical properties of the cartridge case wall of the HEI-T 40 mm

Positions	Distance to top of cartridge case [mm]	Mechanical properties	
		σ_b [MPa]	δ [%]
1	10	$340 \div 400$	≥30
2	75	$350 \div 420$	≥30
3	150	$370 \div 470$	≥25
4	230	$400 \div 500$	≥20
5	325	$540 \div 660$	≥10

Widyastuti et al. studied the effects of annealing process parameters including annealing temperature and heat holding time on the microstructure and mechanical properties of CuZn35 brass alloy applied in cartridge case manufacturing processes. The annealing temperature ranges from 300 °C to 600 °C while the heat holding time is fixed at 60 mins. The results showed the elimination of precipitation phenomenon, reduced strength and hardness along with significantly improved ductility [9]. Sahira Hassan Ibrahim et al. used the Taguchi method to evaluate the mechanical properties of AA7075 aluminum alloy under the influence of the heat treatment process [10]. The optimal values of mechanical properties were evaluated through tensile strength and hardness. This study contributes to the fabrication of AA7075 aluminum alloy suitable for a range of industrial applications. The effect of cold deformation and heat treatment on the microstructures and mechanical properties of Au-15Ag-12Cu-6Ni alloy sheets is given by Haodong Chen et al. [11]. The ductility of the alloy increases and the hardness decreases after heat treatment. Thus, the heat treatment process has restored the required hardness for the next forming processes.

In this work, the effects of process parameters on the mechanical properties of the 40 mm L70 cartridge case are studied. The Taguchi method is used to evaluate and optimize the effects of input parameters on the objective function. The input parameters include the ironing ratio *m* during deep drawing process, the annealing temperature *T* [°C], and the heat holding time *t* [min]. Meanwhile, the output parameters are the strength σ_b [MPa] and the relative elongation δ [%] at the position 325 mm from the top of the cartridge case. The "larger is better" condition combined with the technical requirements of the cartridge case is used to determine the optimal process parameters during deformation and heat treatment to obtain the best mechanical properties of the cartridge case. The research results contribute to optimizing the forming process to ensure reliable performance of the cartridge case under operational conditions.

2 Materials and Methods

The material used to manufacture the cartridge case of the HEI-T shells is brass L68. However, this material often has the phenomenon of "season cracking" [12, 13]. This is a form of stress-corrosion cracking of brass cartridge cases. In this study, LK75-05 alloy produced in Vietnam was used to manufacture the cartridge case of the HEI-T 40 mm round. The chemical composition of LK75-05 and L86 is presented in Tab. 2. The copper alloy LK75-05 is based on the alloy of copper and zinc, but with addition of a very small amount of silicon, which has changed the Cu-Zn phase diagram. Silicon has the effect of limiting cold embrittlement, increasing ductility, and reducing the possibility of cracking during the ironing process. Based on the Cu-Zn phase diagram, the equivalent Zn content in LK75-05 alloy is 29.25 %, similar to L68 alloy. However, the actual zinc content in LK75-05 alloy is 25.03 %, so it avoids the sensitivity to seasonal cracking in the climatic conditions in Vietnam [14-16].

Tab. 2 Analyzed chemical composition of LK75-05 alloy (in weight percent, wt%)

Alloys	**Cu**	**Si**	**Zn**	**Pb**	**Sn**	**P**	**S**
LK75-05	74.25	0.45	25.03	0.007	0.004	0.0015	0.0001
L68	70.62	–	29.35	0.005	0.005	0.0010	0.0002

The process of forming the cartridge case involves five steps of ironing. Between the ironing steps, heat treatment is usually performed to restore the plasticity of the material for the next step. However, between step 4 and step 5, there is no heat treatment so that the cartridge case can achieve the required mechanical properties. Therefore, this study chose to investigate the process parameters of deformation and heat treatment between ironing step 3 and step 4. The mechanical properties of the cartridge case were evaluated through the strength and relative elongation during tensile tests.

The Taguchi method, since it does not test all possible experimental combinations, provides only a directional estimate of how an input parameter affects the output rather than an exact measurement. However, by analyzing the signal-to-noise (*S/N*) ratio, technologists can identify the trends and relative impacts of each process parameter on the output. This allows researchers to quickly pinpoint the key parameters and their ranges that will yield the best results. By assessing the individual effects of these parameters, it becomes possible to determine the optimal combination for achieving the desired output characteristics [17, 18].

The paper selected the following input parameters: the ironing ratio *m* of the ironing step 4, the annealing temperature *T* [°C], and the heat holding time *t* [min] after step 3 and before step 4. The output parameters were the tensile strength σ_b [MPa] and the relative elongation δ [%] of tensile tests examined after step 5 of ironing. The value ranges of the parameters influencing the objective function are determined and discretized into distinct levels, as presented in Tab. 3. The experimental design matrix is then constructed based on the number of influencing parameters and the corresponding number of levels. With three affecting parameters and three transformation levels, the experimental matrix is the orthogonal matrix L9 [19-21] with nine experiments as shown in Tab. 4. Experiments are to be conducted to collect data of output parameters. In some cases, each experiment is repeated *n* times. The data are analyzed according to the *S/N* ratio, using the objective function "bigger is better" according to Eq. (1). Then the optimal experimental values of the parameters are determined. To determine the effect of the parameters on the output results, we use the average value analysis to determine the level of the effect of the parameters on the output results [22, 23].

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \tag{1}$$

where n – the number of repetition experiments (n = 1); y_i – the measurement value of the elongation to fracture of the i-th experiment.

Tab. 3 Input process parameters and levels

Parameters	Coding symbol	Levels		
		Level 1	Level 2	Level 3
Ironing ratio [m]	X_1	0.588	0.647	0.706
Annealing temperature *T* [°C]	X_2	450	550	650
Heat holding time *t* [min]	X_3	30	60	90

Tab. 4 Experimental design Taguchi L9

E. no.	Process parameters		
	X_1	X_2	X_3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Fig. 1 shows the equipment and instruments used for this study. The LK75-05 alloy chemical composition was analyzed using the LAB LAVM11 emission spectrometer (Fig. 1a). Tensile tests were performed on a TT-HW2-1000 tensile and compression device (Fig. 1b). The equipment for the ironing and heat treatment processes was a CRU400 hydraulic press and a CF15080 well furnace, respectively (Figs 1c and 1d). Three ironing dies were fabricated corresponding to three variations of the ironing ratio (Fig. 1e).

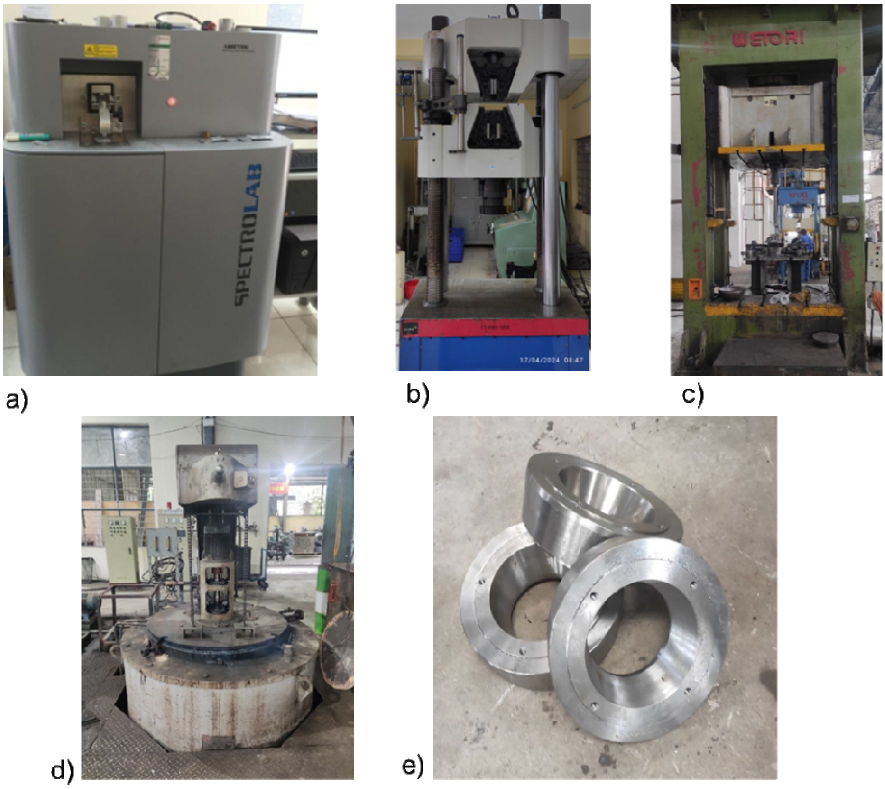

Fig. 1 Experimental equipment and tools

3 Results and Discussion

The experiment was carried out according to the Tauguchi method of the ironing step 4 with the process parameters of deformation and heat treatment changed according to Tab. 4. The experimental samples after the step 5 of ironing process are shown in Fig. 2. The tensile test specimens were made from the parts of the cartridge case after step 5 thinning at the position of 325 mm from the top of the cartridge case (Fig. 3). The results of tensile strength σ and relative elongation δ are shown in Fig. 4.

Based on the theoretical study of the Taguchi experimental planning method and the mechanical properties of the HEI-T 40 mm shells, the method of calculating the *S/N* ratio for the “bigger is better” characteristic using Eq. (1) was selected. This method was used to evaluate the effect of process parameters on the tensile strength and relative elongation of the cartridge case after the ironing steps.

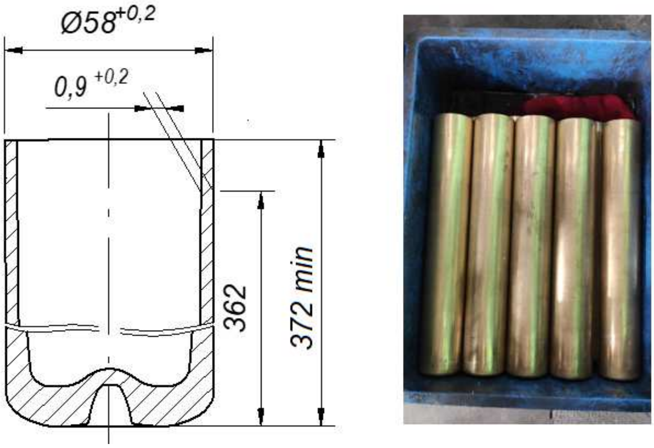

Fig. 2 Product after the ironing step 5

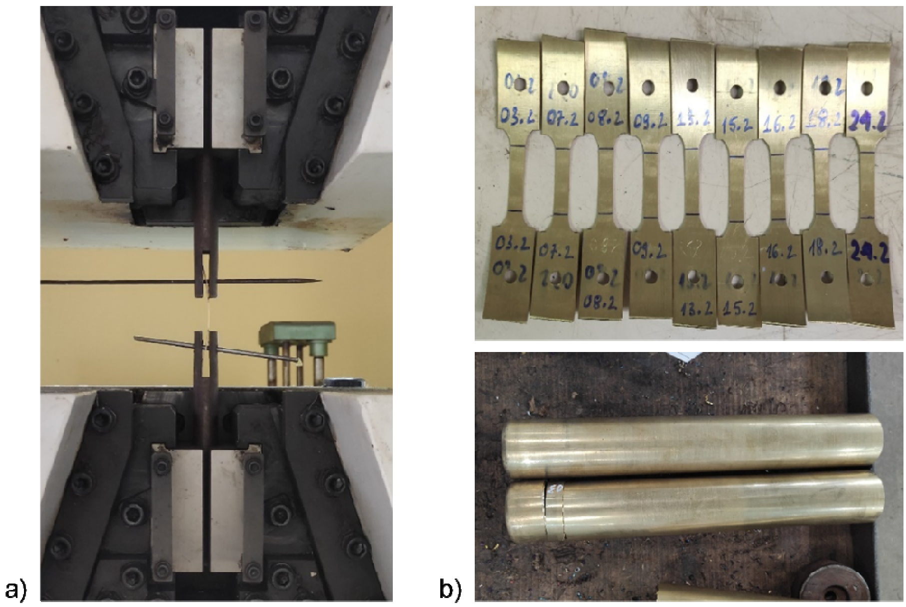

Fig. 3 Tensile test fixture (a) and tensile specimens (b)

3.1 Effect of Process Parameters on the Strength of the Cartridge Case

Using Eq. (1), we can calculate the *S/N* value according to the "bigger is better" characteristic (Tab. 5). From Tab. 5, we create an analysis table to evaluate the *S/N* results according to the levels of change (Tab. 6). The graph of the effect of process parameters on the tensile strength of the cartridge case after the ironing steps, at a position 325 mm from the top of the cartridge case, is shown in Fig. 5.

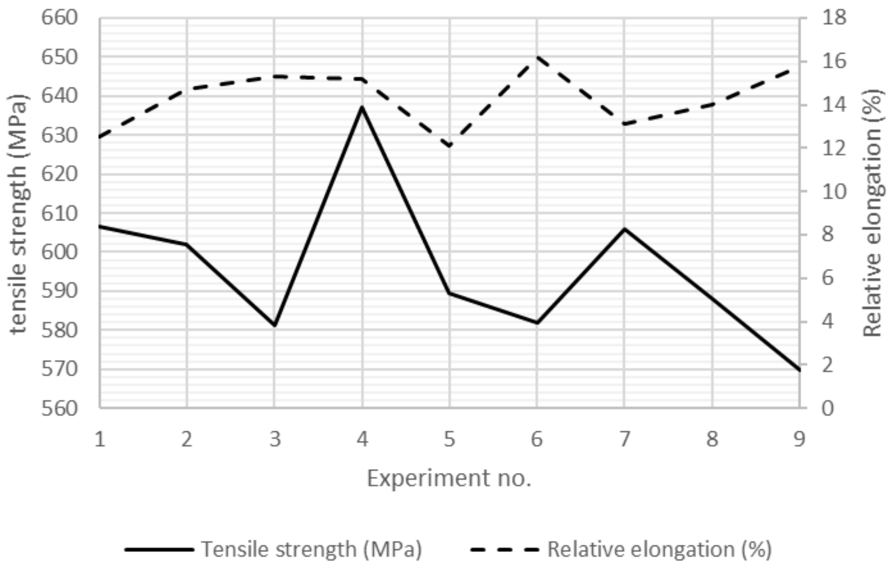

Fig. 4 Experimental results

Tab. 5 S/N results table by "bigger is better" characteristic for tensile strength

Exp. no.	1	2	3	4	5	6	7	8	9
S/N	55.66	55.59	55.28	56.08	55.41	55.30	55.65	55.39	55.11

Tab. 6 Analysis table of S/N results for tensile strength

Variation levels	Average *S/N* at levels		
	X_1	X_2	X_3
1	55.51	55.80	55.45
2	55.60	55.46	55.60
3	55.39	55.23	55.45
Mean	55.50	55.50	55.50
Max	55.60	55.80	55.60
Delta	0.21	0.56	0.15
% Effect	22.89	61.01	16.10

The percentage of effect of process parameters on the strength of the cartridge case after ironing is ranked in the following order: annealing temperature (61.01 %);

ironing ratio (22.89 %); and heat holding time (16.10 %). The strength of the cartridge case decreases as the annealing temperature increases. This is consistent with the theory because increasing the annealing temperature leads to a decrease in the physical and mechanical properties of the material. The strength of the product increases when the ironing ratio increases from 0.588 to 0.647 and decreases when the ironing ratio continues to increase. The strength of the product increases when the heat holding time increases from 30 to 60 mins and decreases when the heat holding time continues to increase. During the cold deformation process, hardening is the main cause of the increased strength of the deformed product. Therefore, a small ironing ratio causes large hardening, leading to an increase in the strength of the cartridge case.

Due to the simultaneous interaction of three factors – ironing ratio, annealing temperature, and heat holding time – with annealing temperature having the most significant effect, there is always a condition under which the material strength reaches its optimal value when the ironing ratio (*m*) is 0.647 and the heat holding time (*t*) is 60 minutes.

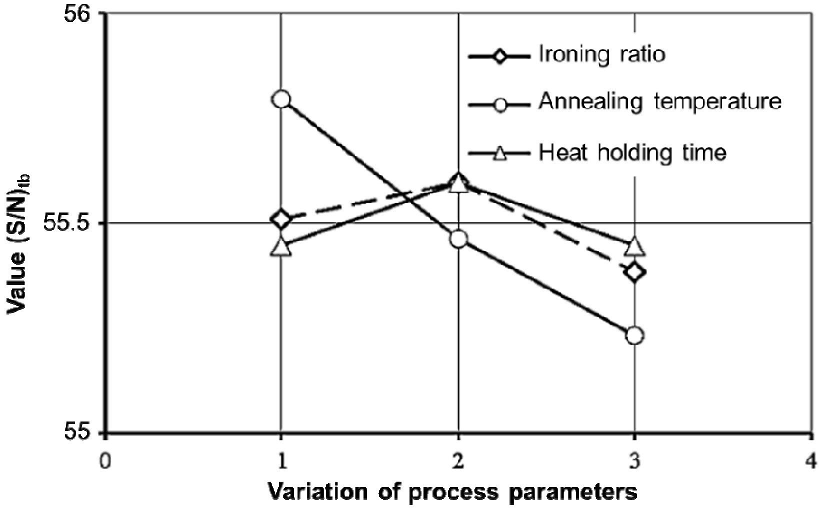

Fig. 5 Effect of process parameters on tensile strength

The optimal solution is obtained with the largest variation of the process parameters with the average *S/N* ratio. It is the solution with the process parameters of the ironing ratio, annealing temperature, and heat holding time having values 0.647, 450 °C, and 60 min, respectively. The optimal strength value σ_{op} is calculated according to Eq (2). The noise ratio $(S/N)_{op}$ of the optimal method is determined according to Eq. (3). The Max_{X1}, Max_{X2}, and Max_{X3} are the values in Tab. 6.

$$\sigma_{op} = 10 \cdot \exp \frac{(S/N)_{op}}{20} = 630.95\,[\mathrm{MPa}] \tag{2}$$

$$\left.\begin{aligned} (S/N)_{op} &= m + \left(\max_{X_1} - m\right) + \left(\max_{X_2} - m\right) + \left(\max_{X_3} - m\right) \\ (S/N)_{op} &= \max_{X_1} + \max_{X_2} + \max_{X_3} - 2m \end{aligned}\right\} \tag{3}$$

3.2 Effect of Process Parameters on the Relative Elongation of the Cartridge Case

Using Eq. (1), we can calculate the *S/N* value according to the "bigger is better" characteristic of the relative elongation of the cartridge case (Tab. 7). From Tab. 7, we create an analysis table to evaluate the *S/N* results according to the levels of change (Tab. 8). The graph of the effect of process parameters on the strength of the cartridge case after the ironing steps, at a position 325 mm from the top of the cartridge case, is shown in Fig. 6.

The percentage of the effect of process parameters on relative elongation is ranked in the following order: annealing temperature (51.2 %); ironing ratio (6.75 %); and heat holding time (42.04 %). Relative elongation increases as the annealing temperature increases.

The temperature rises sufficiently to reach the recrystallization point, allowing the metal to regain its plasticity and thereby increasing its relative elongation.

Relative elongation increases as the ironing ratio increases from 0.588 to 0.647 and decreases as the ironing ratio continues to increase. Relative elongation increases as heat holding time increases from 30 to 60 min and decreases as heat holding time continues to increase. Heat holding time increases with increasing annealing temperature, leading to a second recrystallization of the metal material, the crystal grains grow larger, leading to a decrease in plasticity, thus decreasing relative elongation.

Tab. 7 S/N results table by "bigger is better" characteristic for relative elongation

Exp. no.	1	2	3	4	5	6	7	8	9
S/N	21.92	23.32	23.69	23.64	21.66	24.17	22.34	22.90	23.99

Tab. 8 Analysis table of S/N results for relative elongation

Variation levels	Average *S/N* at levels		
	X_1	X_2	X_3
1	22.98	22.63	23.00
2	23.15	22.63	23.65
3	23.07	23.95	22.56
Mean (m)	23.07	23.07	23.07
Max	23.15	23.95	23.65
Delta	0.17	1.32	1.09
% Effect	6.75	51.20	42.04

The optimal solution will be the solution with the largest variation of the process parameters with the *S/N* ratio according to the average relative elongation. It is the solution with the process parameters of the ironing ratio, annealing temperature, and heat holding time having values 0.647, 650 °C, and 60 min, respectively. Similar calculations according to Eqs (2) and (3) give the optimal relative elongation value δ_{op} of 17.01 %.

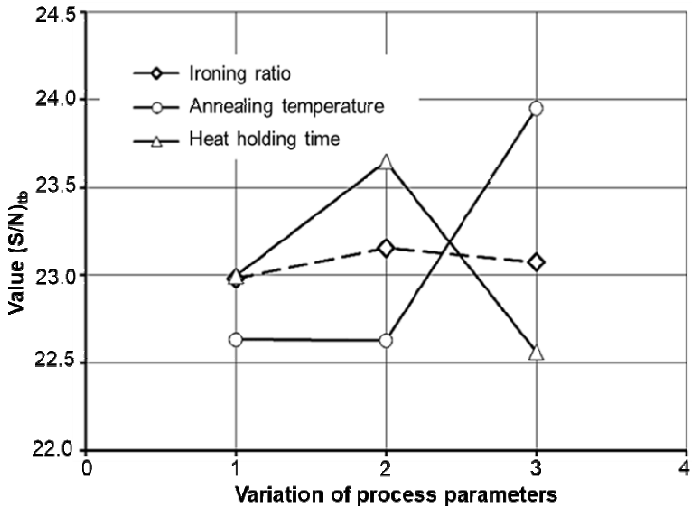

Fig. 6 Effect of process parameters on relative elongation

The optimal solution will be the solution with the largest variation of the process parameters with the *S/N* ratio according to the average relative elongation. It is the solution with the process parameters of the ironing ratio, annealing temperature, and heat holding time having values 0.647, 650 °C, and 60 min, respectively. Similar calculations according to Eqs (2) and (3) give the optimal relative elongation value δ_{op} of 17.01 %.

3.3 Optimization

The two sets of optimal process parameters for tensile strength and relative elongation have different annealing temperatures. However, from the experimental results in Tab. 5 and the technical requirements of the cartridge case in Tab. 1, it can be seen that all values of relative elongation meet the requirements (≥10 %). Therefore, the optimal process parameter set is selected according to the optimal parameter set of durability with the process parameters of the ironing ratio, annealing temperature, and heat holding time having values 0.647, 450 °C, and 60 min, respectively.

With the optimal parameter set along with the data in Fig. 4, it can be seen that the relative elongation reaches 15.2 %, meeting the technical requirements of the cartridge case (>10 %). Thus, the above set of deformation and heat treatment parameters is the optimal set of process parameters to ensure the technical requirements when forming the cartridge case of the HEI-T 40 mm shells.

4 Conclusions

The paper determines the ranges of process parameter changes including ironing ratio m, annealing temperature T [°C], and heat holding time t [min] affecting the mechanical properties of the cartridge case after the ironing process. From there, the experimental processes were built based on the Taguchi experimental planning method.

Taguchi's experimental planning method was used to determine optimal deformation and heat treatment process parameters.

Simultaneously, the effect of process parameters on the tensile strength and relative elongation of the cartridge case for HEI-T 40 mm shells, fired from the 40 mm L70 anti-aircraft gun, was analyzed after ironing.

With the characteristic of "bigger is better" combined with the technical requirements of the dose shell, the optimal strength σ_{op} = 63.7 MPa and relative elongation δ_{op} = 15.2 % at the position 325 mm from the top of the cartridge case are achieved with the following process parameters: ironing ratio m of 0.647 of the ironing step 4, annealing temperature T of 450 °C and heat holding time t of 60 min after the ironing step 3. The annealing temperature has the greatest effect on the strength of the cartridge case wall after ironing process.

Based on the findings of this study, the results can be applied to the production of cartridge cases for HEI-T 40 mm shells used in the 40 mm L70 anti-aircraft gun, utilizing the LK75-05 alloy. The actual performance of LK75-05 alloy cartridge cases can be evaluated once they are deployed in military applications. Furthermore, the research methodology presented here can be extended to the development of similar products.

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References

[1] ZELENOVIĆ, N., A. KARI and A. STANOJEVIĆ. Optimization of the Elevating Mass Balance of the Anti-Aircraft Gun BOFORS 40 mm L/70. *Scientific Technical Review,* 2018, **68**(3), pp. 25-30. DOI 10.5937/str1803025Z.

[2] ROZWADOWSKI, P. *Polskie Armaty Przeciwlotnicze 75 mm wz. 36/37 Oraz 40 mm Bofors* (in Polish). Warsaw: Agencja Wydawnicza CB, 2017. ISBN 83-7399-178-6.

[3] CHINN, G. M. *The Machine Gun: History, Evolution and Development of Manually Operated, Full Automatic, and Power Driven Aircraft Machine Guns.* Washington: Government Printing Office, 1951.

[4] HAMILTON, D.T. *Cartridge Manufacture: A Treatise Covering the Manufacture of Rifle Cartridge Cases, Bullets, Powders, Primers and Cartridge Clips, and the Designing and Making of the Tools Used in Connection with the Production of Cartridge Cases and Bullets*. London: Forgotten Books, 2018. ISBN 1-332-05163-4.

[5] PARATE, B.A., S. CHANDEL and H. SHEKHAR. Cartridge Case Design and Its Analysis by Bilinear, Kinematic Hardening Model. *Advances in Military Technology,* 2019, **14**(2), pp. 231-243. DOI 10.3849/aimt.01283.

[6] MOHAMMED, A.S.E. Analysis of Structural State of 60/40 Brass Cartridge Case (BCC) after Being Exposed to High Pressure and Temperature of Firing. *Open Journal of Applied Sciences*, 2019, **10**(10), pp. 1255-1270. DOI 10.4236/ojapps.2019.99058.

[7] PERONI, L., M. SCAPIN, C. FICHERA, A. MANES and M. GIGLIO. Mechanical Properties at High Strain-Rate of Lead Core and Brass Jacket of a NATO 7.62 mm Ball Bullet. *EPJ Web of Conferences*, 2012, **26**, 01060. DOI 10.1051/epjconf/20122601060.

[8] PARATE, B.A., R. POTDAR, S. CHANDEL and H. SHEKHAR. Light Weight Aluminum Cartridge Case Design for IED's Application – ANSYS. *Journal of Modern Mechanical Engineering and Technology*, 2020, **7**, pp. 16-26. DOI 10.31875/2409-9848.2020.07.3.

[9] WIDYASTUTI, R., D.M. FELLICIA, C.F. NOVAL ADRINANDA and A.P. WIBOWO. Mechanical Properties, Microstructural, and Deep Drawing Formability Analysis on the Annealed CuZn35 Brass Alloy for Cartridge Application. *Key Engineering Materials*, 2023, **939**, pp. 31-37. DOI 10.4028/p-21x8y5.

[10] IBRAHIM, S.H., S.H. AHMED and I.A. HAMEED. Evaluated of Mechanical Properties for Aluminum Alloy Using Taguchi Method. *International Journal of Modern Studies in Mechanical Engineering*, 2016, **2**(1), pp. 26-37. ISSN 2454-9711.

[11] CHEN, H., X. CUI, S. HUI, C. LI, W.-J. YE and Y. YU. Effect of Cold Deformation and Heat Treatment on the Microstructures and Mechanical Properties of Au-15Ag-12Cu-6Ni Alloy Sheets. *Materials*, 2024, **17**(2), 356. DOI 10.3390/ma17020356.

[12] YOSHIMURA, Y., K. KITA and A. INOUE. White-Color Cu-Zn-Mn Alloys with Low Season Cracking Susceptibility. *Journal of the Society of Materials Science Japan*, 2004, **53**(2), pp. 188-192. DOI 10.2472/jsms.53.188.

[13] DAVALOS-MONTEIRO, R. Observations of Corrosion Product Formation and Stress Corrosion Cracking on Brass Samples Exposed to Ammonia Environments. *Materials Research*, 2019, **22**(1), e20180077. DOI 10.1590/1980-5373-MR-2018-0077.

[14] BRANDL, E., R. MALKE, T. BECK, A. WANNER and T. HACK. Stress Corrosion Cracking and Selective Corrosion of Copper-Zinc Alloys for the Drinking Water Installation. *Materials and Corrosion*, 2009, **60**(11), pp. 865-872. DOI 10.1002/maco.200805079BOBBY.

[15] BOBBY, K.M. and P.K. SHUKLA. Stress Corrosion Cracking (SCC) of Copper and Copper-Based Alloys. In: *Stress Corrosion Cracking: Theory and Practice*. Cambridge: Woodhead Publishing, 2011, pp. 123-145. ISBN 0-08-101646-8.

[16] LI, D. et al. Stress Corrosion Cracking of Copper–Nickel Alloys: A Review. *Coatings*, 2023, **13**(10), 1690. DOI 10.3390/coatings13101690.

[17] PILLAI, J.U., I. SANGHRAJKA, M. SHUNMUGAVEL, T. MUTHURAMALINGAM, M. GOLDBERG and G. LITTLEFAIR. Optimisation of Multiple Response Characteristics on End Milling of Aluminium Alloy Using Taguchi - Grey Relational Approach. *Measurement*, 2018, **116**, pp. 108-117. DOI 10.1016/j.measurement.2018.04.052.

[18] BAGCI, E. and B. OZCELIK. Analysis of Temperature Changes on the Twist Drill Under Different Drilling Conditions Based on Taguchi Method During Dry Drilling of Al 7075-T651. *The International Journal of Advanced Manufacturing Technology*, 2005, **27**(1), pp. 318-325. DOI 10.1007/s00170-005-2569-1.

[19] BHARDWAJ, V., A. CHANDRA and N. YADAV. Investigating the Effect of Process Parameters on the Mechanical Properties of A713 Sand Cast Aluminium Alloy by Using Taguchi Method. *International Journal of Advances in Engineering and Technology*, 2013, **6**(5), pp. 2274-2285. ISSN 2231-1963.

[20] GAO, G., F. XU and J. XU. Parametric Optimization of FDM Process for Improving Mechanical Strengths Using Taguchi Method and Response Surface Method: A Comparative Investigation. *Machines*, 2022, **10**(9), 750. DOI 10.3390/machines10090750.

[21] AYAZ, M., N. BANIMOSTAFA ARAB and D. MIRAHMADI KHAKI. Application of Taguchi Method for Investigating the Mechanical Properties of a Micro-Alloyed Steel. *Archives of Metallurgy and Materials*, 2014, **59**(2), pp. 579-582. DOI 10.2478/amm-2014-0144.

[22] REDDY, A.C.S., S. RAJESHAM, P.R. REDDY, T.P. KUMAR and J. GOVERDHAN. An Experimental Study on Effect of Process Parameters in Deep Drawing Using Taguchi Technique. *International Journal of Engineering, Science and Technology*, 2015, **7**(1), pp. 23-31. DOI 10.4314/ijest.v7i1.3.

[23] TIEN, N.M., N.T. AN, T.D. HOAN, L.D. GIANG and L.T. TAN. Experimental Study on Effects of Process Parameters on Superplastic Deformation Ability of 7075 Aluminium Alloy Using Taguchi Method. In: *International Conference on Engineering Research and Applications*. Cham: Springer, 2019, pp. 328-334. DOI 10.1007/978-3-030-37497-6_38.