中正嶺學報 第五十三卷 第一期 民國 113. 05
JOURNAL OF C.C.I.T., VOL. 53, NO. 1, MAY, 2024
DOI：10.30188/JCCIT.202405_53(1).0005

Application of Cryogenic Treatment to Enhance Target Accuracy of 410 Stainless Steel Sniper Barrel

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ABSTRACT

Cryogenic treatment can effectively improve the shooting accuracy and extend the shooting lifespan of the barrel. This study mainly aims to use cryogenic treatment for the SS410 stainless steel sniper barrel manufactured by the 205 Arsenal, and to evaluate the feasibility of using cryogenic treatment to improve the shooting accuracy and shooting lifespan of the SS410 stainless steel sniper barrel. The wear resistance test, vickers hardness test, optical microscope (OM), shooting test and endoscope were used to verify the benefits of cryogenic treatment for SS410 stainless steel sniper barrel. The experimental results show that after cryogenic treatment, the SS410 stainless steel sniper barrel has a lower coefficient of friction, smaller grain size, better shooting accuracy and less copper fouling residue. However, there is no obvious change in hardness. Based on the above analysis, the SS410 stainless steel sniper barrel after cryogenic treatment can effectively improve its shooting accuracy and the ease of cleaning the barrel.

Keywords: 410 stainless steel, Cryogenic treatment, Accuracy, Wear resistance

應用超冷處理提升 410 不銹鋼狙擊槍管精度之研究

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摘　要

超冷處理具有可消除殘留應力、提升尺寸穩定性、增加耐磨耗性能等優點，許多文獻指出超冷處理可有效提高槍管之射擊精度、延長槍管射擊壽命且已將此技術應用於各式槍管或槍枝零配件中。本研究的目的主要是針對軍備局205兵工廠所生產之410不銹鋼狙擊槍管進行超冷處理，評估應用超冷處理技術提升410不銹鋼狙擊槍管射擊精度及射擊壽命的可行性。透過耐磨耗試驗、維克式硬度試驗、微觀組織觀察、實際射擊試驗及槍膛內視鏡觀察，驗證超冷處理對於410不銹鋼狙擊槍管的效益。研究實驗結果表明，經由超冷處理後410不銹鋼狙擊槍管具有較低的摩擦係數、較小的晶粒大小、較佳的射擊精度及較少的銅污殘留量，惟硬度方面無明顯變化。綜合以上分析，經由超冷處理後之410不銹鋼狙擊槍管可有效提升其射擊精度及增加槍管易潔性。

關鍵詞：410不銹鋼、超冷處理、精度、耐磨耗性

文稿收件日期 112.04.18; 文稿修正後接受日期 113.03.29; * 通訊作者
Manuscript received Apr 18, 2023; revised Mar 29, 2024; * Corresponding author

I. INTRODUCTION

A gun barrel belongs to metal pipes, and its manufacturing process includes a complex combination of physics, metallurgy, engineering, and ballistics. The main function of the barrel is to force bullets to accelerate out of it. A fully functional barrel contains three parts: ammunition chamber, throat, and rifling, as shown in Figure 1 below. The function of ammunition chamber is to store bullet shells, and the throat which the main function is to store bullets and to provide good airtightness is located behind the ammunition chamber. When the throat is damaged, it will reduce the airtightness of the barrels, the muzzle velocity of shooting, and shooting accuracy. The last part is rifling that the main function is to make the fired bullet rotate at a high speed, increasing stability and accuracy when the bullets are out of the barrel.

A sniper rifle plays a decisive role in all types of wars. The main function of the sniper rifle is to kill automatic weapon or heavy weapon operators more accurately, which in turn greatly reduce the enemy combat capabilities, and quickly dominate the battlefield [1]. To compare with rifles, the sniper rifle has higher requirements for shooting accuracy and precision. At present, the materials used in the production of barrels in the US commercial market are mainly SS416 and SS410 stainless steels. Because the SS416 stainless steel has a higher sulfur content, the broach cutting rifling and button rifling processing methods of the barrel could give SS416 stainless steel better processability. However, the SS410 stainless steel has lower sulfur content so it is less likely to produce cracks during forging and processing of the barrel, which in turn to reduce the risk of bore premature during shooting.

Cryogenic treatment is a new process of treating workpieces to cryogenic temperature to improve the materials properties by decreasing the residual stress, stabilizing dimensional accuracy, increasing hardness, fatigue resistance, wear resistance and the life of tool. The cryogenic treatment mainly has the following advantages:

(1) Increase the durability:
Cryogenic treatment can promote the steel transformation of retained austenite structure present into martensite structure and create a more uniform grain structure. The martensite transformation results in higher hardness and stable structure of the steel. Hence, the durability will be enhanced.

(2) Improve wear resistance:
The precipitation of fine Eta carbide can be promoted by the cryogenic treatment and these fine carbides act as binders that can support the martensite matrix to increase the wear resistance of the treated material.

(3) Relieve the stress:
The residual stress is created when material solidifies from liquid phase into solid phase or by different process such as heat treating. The residual stress can result in weak areas that are prone to failure. Cryogenic treatment can decrease these weakness areas by reducing the residual stress.

Beside the ferrous metals, the cryogenic treatment has also been used to treat copper, aluminum, magnesium alloy and polymer to improve their performances such as wear resistance, thermal or electrical conductivity. Due to the above advantages, Cryogenic treatment has been widely used in different industries such as aerospace, defense, automotive, cutting tools, musical instrument, sports…etc. [2-12].

Nevertheless, one of the drawbacks for the cryogenic treatment is high operating cost. Some misconceptions about cryogenic processing are that it can change the size of parts and lead to brittle components. Those misconceptions can be a stumbling block for people who are undecided about the feasibility of cryogenic treatment.

There are many studies which have pointed out that cryogenic treatment can effectively improve the shooting accuracy of the barrel. The 300° BELOW cryogenic treatment company in the USA showed the benefits of the cryogenic treatment for shotguns (as shown in Figure 2). The shooting patterns shifted by as much as 10 to 12 inches before CRYO-Barrel treatment. However, the shooting patterns shifted by only 3/4 inch after CRYO-Barrel treatment [13]. The American Cryogenics International company also indicated that after the cryogenic treatment AR15 rifle barrel can effectively improve the shooting accuracy and have double holes phenomenon and the shoot results are shown in Figure 3 [14]. These studies are conducted on

DOI：10.30188/JCCIT.202405_53(1).0005

the barrels of commercial guns in the United States. Conversely, the research on cryogenic treatment of military guns is very rare, especially cryogenic treatment of 410 stainless steel sniper barrels. Thus, the purpose of this research is mainly to study the feasibility of applying cryogenic treatment to improve the shooting accuracy. Through hardness, wear resistance, microstructure observation and actual shooting tests, the effect of cryogenic treatment on the 410 stainless steel sniper rifles can be verified.

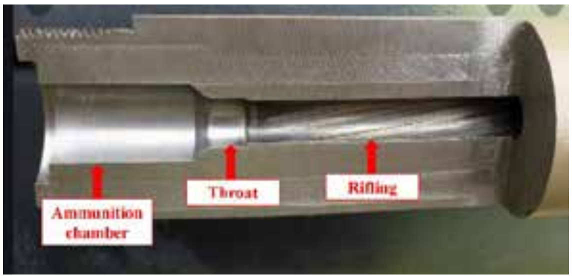


Fig.1. Main Structure of a gun barrel

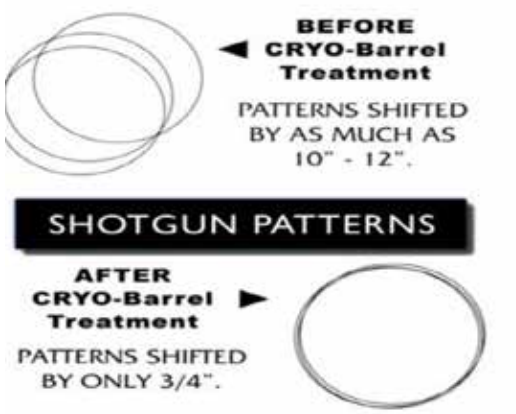


Fig.2. The impact points of shotgun barrels before / after cryogenic treatment [13]

Fig.3. Shooting results of the AR15 barrel before/ after cryogenic treatment [14]

II. EXPERIMENTAL METHOD

2.1 Specimens preparation

The specimens were prepared to measure the hardness, the wear resistance and to observe the microstructure before/after cryogenic treatment. The specimens were needed to polish below Ra 0.8 μm to conform ASTM G99-17 standard [15]. Specimen's roughness was measured by JENOPTIK HOOMMEL T8000 RC. There were three specimens (untreated, process A and process B) in this research and the roughness of each specimen was shown in Table 1.

Table 1. The roughness of each specime

Roughness of specimens (μm)	
Untreated	0.063
Process A	0.043
Process B	0.042

2.2 Cryogenic treatment

Specimens and SS410 sniper barrels were put into cryogenic treatment processor (Applied Cryogenics CP-200vi) and using liquid nitrogen as coolants in cryogenic treatment process. The processing parameters for different cryogenic treatments (A & B) were shown in Table 2. Compared with process A, process B had a lower cooling rate and longer soaking time.

Table 2. Cryogenic treatment process

Step	Process A	Process B
Cooling down (From room temperature to -196˚C)	7.5 hrs	11 hrs
Soaking (Stay at -196˚C)	2 hrs	8 hrs
Back to room temperature (From -196˚C to room temperature and warm up through air temperature)	10 hrs	10 hrs

2.3 Hardness measurement

Vickers hardness tester (Future-Tech FM-300) was used to measure the hardness of the specimens before/after cryogenic treatment according to ASTM E384-11 [16]. The load and duration were 300g and 15 seconds respectively.

Three specimens were tested for each process and a total of 5 points were tested for each specimen.

2.4 Wear resistance test (Ball on disk)

The wear resistant test parameters were performed according to the ASTM G99-17 standard [15]. The wear resistant test were carried out using a 9.8-N load and a rotational rate of 0.1 m/s for 1 hour. After the wear resistant test, the coefficient of friction was used to compare the benefits of different processes on the SS410 specimens.

2.5 Microstructure observation

OM (Optical microscope / ZEISS AXIO Imager.A1) was used to compare the different specimens from process A and process B. In order to reveal the microstructure, the specimens were needed to be ground, polished and etched by ferric chloride solution. Metallographic observation of the processes A, B and untreated followed by the ASTM E112-12(2021) [17] and using the 100× magnification.

2.6 Shooting test

In this research, SS410 sniper barrels were made by GFM SHK-10 cold forging machining and according to 205 arsenal sniper shooting tests standard. The shooting tests were performed with the distance to 200 meters, length of gun barrels about 600mm, NATO 7.62 × 51mm (M118LR) bullets, and adopting the mean radius of dispersion (Mean Radius, MR) shooting specification. In addition, there are 15 barrels in the shooting test (Five barrels per process), each barrel shoots two targets (10 rounds per target).

III. RESULTS AND DISCUSSION

3.1 Hardness test

The hardness test results are shown in Table 3. The results show that there are no obvious increased in hardness of the specimens after cryogenic treatment.

Table 3. Shooting results of the AR15 barrel before/ after cryogenic treatment [14]

(Unit : HV)	Untreated	Process A	Process B
SS410	273.38	268.80	272.18
A total of 15 points (3 specimens) are tested for each process.			

3.2 Wear resistance test

The wear resistance test results are shown in Table 4. These results indicate that the coefficient of friction is reduced from 1.02 (untreated) to 0.949 (process A) and 0.747 (process B). In this test, we can find that the coefficient of friction of process B with a lower cooling rate and longer soaking time, is the lowest than the untreated and process A. The lower coefficient of friction indicates higher wear resistance and thus process B has a better wear resistance performance than untreated and process A.

Table 4. The coefficient of friction of specimens with different processes

Specimen	Coefficient of friction
Untreated	1.02
Process A	0.949
Process B	0.747

3.3 Metallographic observation

The metallographic microstructures results for untreated, A, and process B are shown in Figure 4 to Figure 6. Then, these figures are used to compare with the standard graphics shown in the ASTM E112-12(2021) [17]. The average grain size of each specimen is shown in Table 5. According to the Table 5, the results indicate that the average grain size reduced from 5.0 to 6.5 and 7.0 for untreated, process A and process B respectively (a bigger number means a smaller grain size). The wear resistance results can also been confirmed by the grain size results. Wear resistance increases with decreasing grain size.

DOI：10.30188/JCCIT.202405_53(1).0005

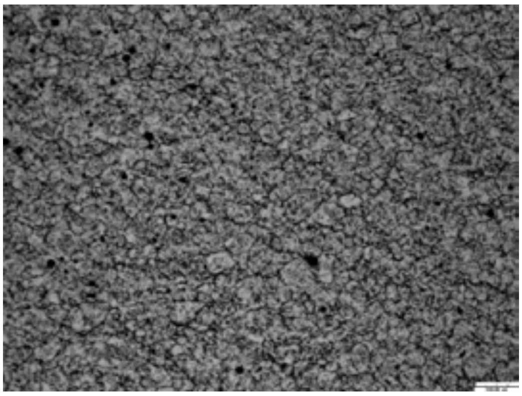


Fig.4. Metallographic microstructure with untreated specimen (100X)

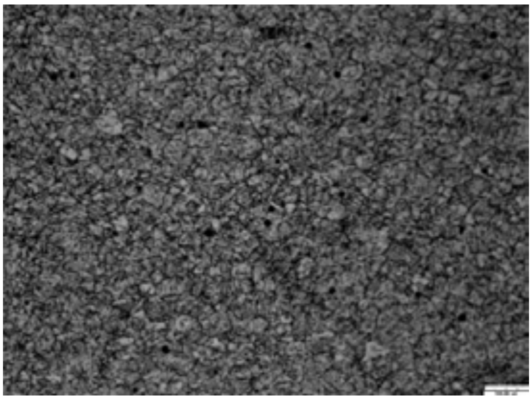


Fig.5 Metallographic microstructure with process A specimen (100X)

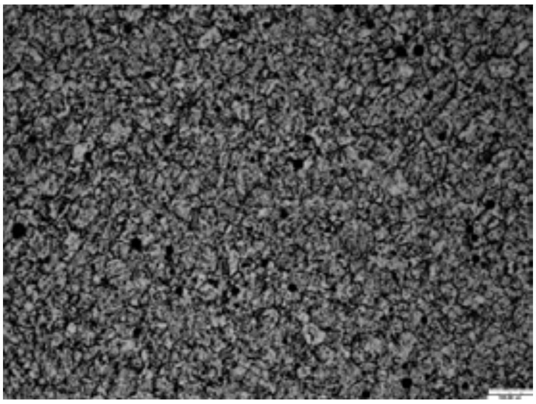


Fig.6. Metallographic microstructure with process B specimen (100X)

Table 5. Average grain size of the specimens with different processes

Specimen	Average grain size number
Untreated	5.0
Process A	6.5
Process B	7.0

3.4 Shooting test

The shooting test results are shown in Tables 6~8. These results indicate that the MR value is reduced from 2.64 (untreated) to 2.24 (Process A) and 2.30 (Process B). Overall, the shooting precision of untreated barrel is worse than that of cryogenic treated ones (processes A and B). Although the process B (longer soaking time) can effectively reduce the friction coefficient, the process A (shorter soaking time) seems to have a better shooting accuracy than process B (both the MR values of process A and process B are very close). However, if you observe from double holes phenomenon, the process A performance of hole dispersion is also much better than untreated process and slightly better than process B. From two aspects of test results, it can be seen that the process A of cryogenic treatment has a better shooting accuracy than that of process B. This unexpected discrepancy need to be further elucidated.

Table 6. Shooting test result with untreated process

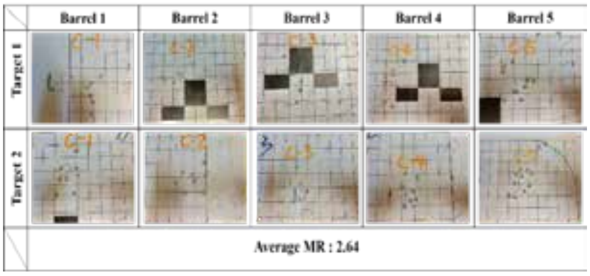


Table 7. Shooting test result with process A

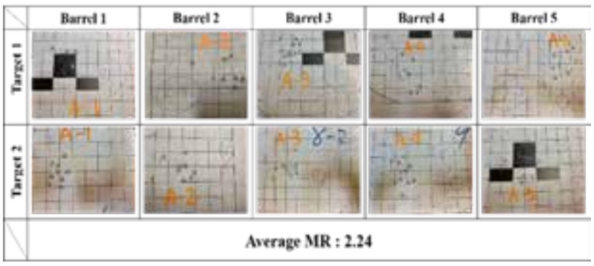
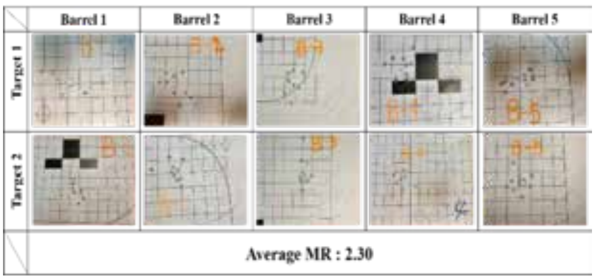


Table 8. Shooting test result with process B



3.5 Endoscope observation

After the shooting test, using the endoscope to observe the barrel with untreated and process A, the observation results are shown in Figure 7 and Figure 8. These results indicate that the amount of copper fouling in surface of inner hole has been significantly reduced after cryogenic treatment. Process B has no obvious copper pollution residue, so only untreated process and process A are displayed here. This result is also consistent with the literatures [8-9]. Therefore, it can be estimated that the cryogenic treatment can reduce the copper fouling on the surface of the barrel.

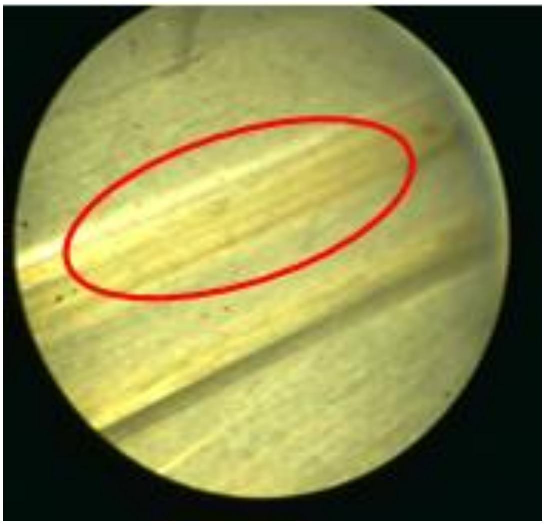


Fig.7. Barrel copper fouling with untreated process

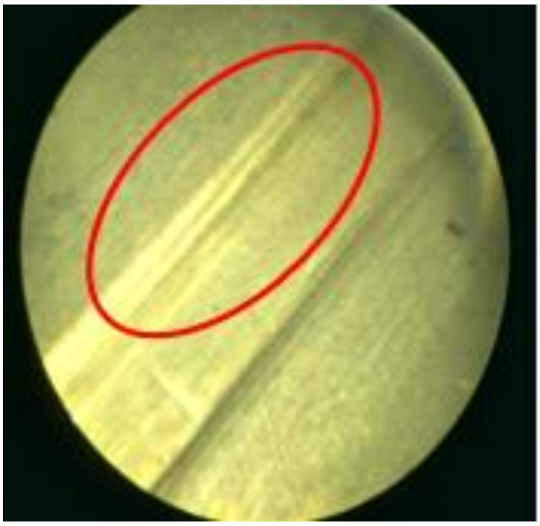


Fig.8. Barrel copper fouling with process A

IV. CONCLUSIONS

In this study, the hardness test, wear resistance test, metallography test and shooting test confirm that cryogenic treatment provides a significant improvement in the shooting accuracy of the SS410 sniper barrel. This is a very valuable and original result, and the main conclusions of this research are as follows:

(1) After cryogenic treatment, the hardness of 410 stainless steel does not increase significantly, the wear resistance increases with the decrease in the coefficient of friction after cryogenic treatment. In addition, the coefficient friction of the process B (slower cooling rate and longer soaking time) is lower than the process A. Therefore, it is can be estimated that the wear resistance of process B will be better than that of the process A.

(2) From the metallography test result, we find that the cryogenic-treated 410 stainless steel has a finer microstructure than that without cryogenic treatment, which is consistent with the wear resistance result.

(3) After the shooting test, the MR values from the process A and the process B have been improved, and the double hole phenomenon has been significantly improved (for both process A and Process B). These results indicate that the cryogenic treatment can effectively improve the accuracy of the barrel when shooting. The process A has a better shooting performance than the process B (although the MR value are very close).

(4) We find that process A has better shooting accuracy and double holes phenomenon, but process B has lower coefficient of friction, finer grain size and no obvious copper residue. In our opinion, process B should have a better performance than process. Further research needs to be conducted to elucidate the unexpected discrepancy between process A and process B, and to explore the optimal cryogenic process.

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