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Analysis of Structural State of 60/40 Brass Cartridge Case (BCC) after Being Exposed to High Pressure and Temperature of Firing

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Abstract

This research presents an experimental and analytical study of the structural state of the 60/40 brass cartridge case, (BCC) after being fired. The oral section of the BCC has the function of confining the gases of firing by expanding against the chamber and sealing the gases. Firing conditions, namely, high pressure and temperature, 3000 bar and 2727˚C, respectively, affect performance properties of the (BCC). These are confining and crack strengths. Experimental study was done on the oral section to address these effects on the structural and mechanical properties of this brass. This alloy is a 60% copper (Cu) and 40% zinc (Zn) alloy and has a two-phase structure, alpha, (α) and beta, (β). Using "before and after" comparison approach; performance properties were tested in cartridge cases prepared before and after firing. These properties are hardness, tensile strength, micro-structural and chemical composition. Comparing the tests' results, after firing demonstrated considerable degrading in performance properties, micro-structural disorder and a remarkable deficiency in the zinc element in the brass structure. This deficiency affects the percentage of beta phase in the alloy which governs the strength of the brass. According to the required properties before firing, it was found that after firing, the brass cartridge case is not qualified for reloading.

Keywords

Structural State, Brass Cartridge Case (BCC), Deficiency of Zinc, Reloading

1. Introduction

The brass 60/40 is a copper alloy composed of 60% copper and 40% zinc with miner impurities. It has a two-phase structure, alpha, (α) and beta, (β). In case of alloy with concentration of Zn from 36% to 40%, the β phase exists after the soidification, and it enhances and increases the mechanical properties with good cold forming. This can be illustrated in Figure 1 and Figure 2 [1].

Cartridge case is commonly manufactured from this alloy for its strength and formability. It has the disadvantage of being defective after firing and not qualified for reloading. Atypical BCC is shown in Figure 3.

Oral Section of the Case

The main problem since 150 years ago, behind scraping brass cartridge cases, was the defects occurred in the brass material after firing [2]. Those defects were faced when improving a technology for cartridge case renewal process by Dr. Jeno Sipos. In their former case of renewal process, there were cracks in the renewed artillery brass cases. In a short storage time, the renewed cases exhibit cracks and hence reloading these cases which were dangerous in firing, for crew and weapon as well. Experiments were made on 85 spent and renewed brass cases; 50 - 60 mm long cracks were found in the mouth and neck of the cases. Metallurgical test was made on case samples and revealed an interecrystalline feature crack which implies stress corrosion cracking as an effect of stresses caused by firing which can be seen in Figure 4.

The study proved that during artillery activity the case suffered deformation which can cause internal stress. Although the temperature is high, about 2626˚C, has no remarkable effect on the case. This is because the time for shelling is very short, about 7.522 ms and the temperature needed for recrystallization is 0.4 melting temperature of brass which is 290˚C. The case temperature was measured immediately after shelling and found to be between 90˚C to 140˚C, which lower than recrystallization temperature. They concluded that the case suffered

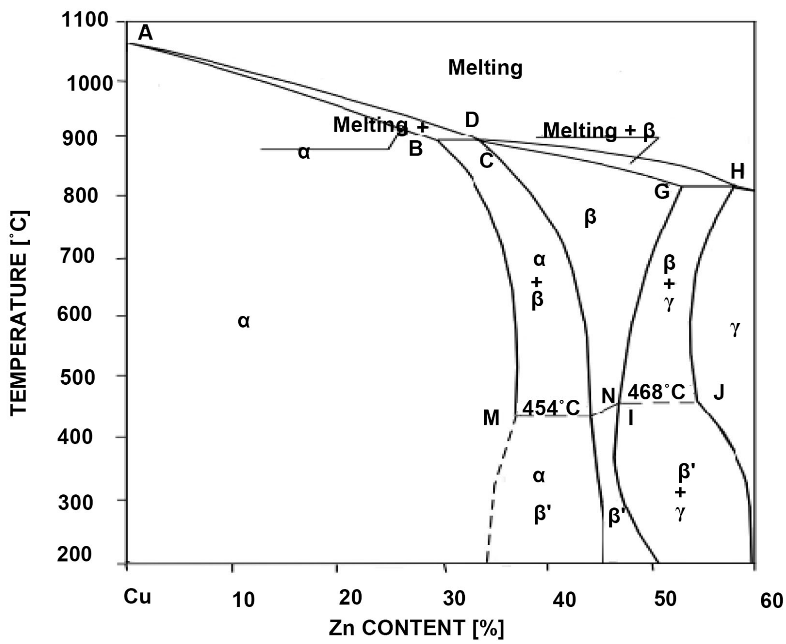


Figure 1. Binary diagram copper-zinc [1].

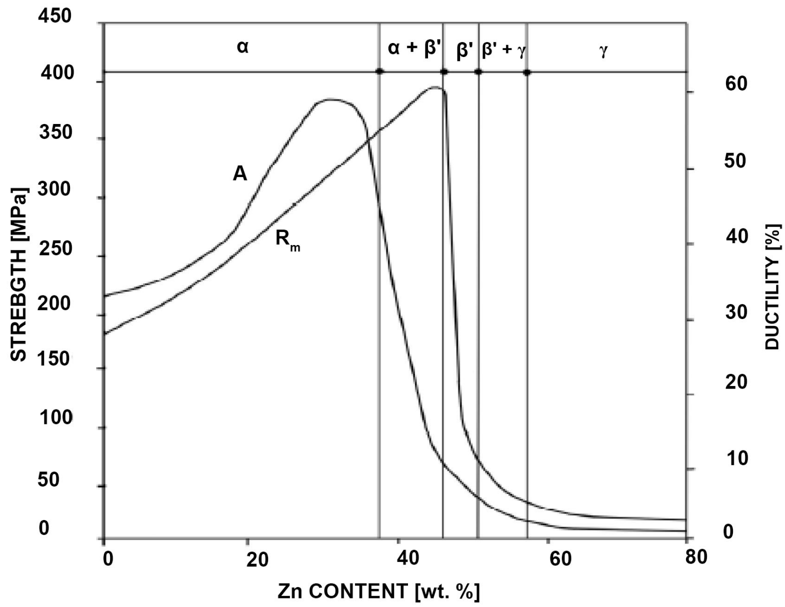


Figure 2. Influence of the Zn content to the brass mechanical properties [1].

Figure 3. Typical fired brass cartridge case.

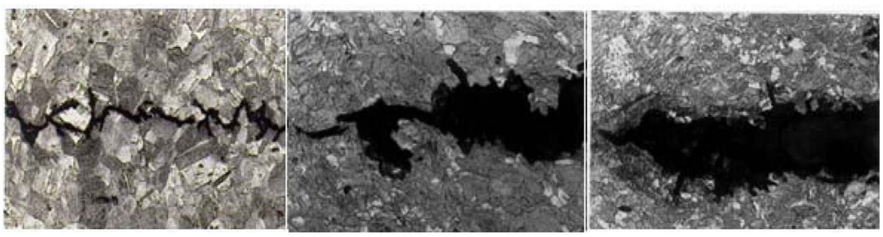


Figure 4. Intercrystalline feature cracks. Amplification = 250x; Etched in 10% ammonium persulphate [2].

only from deformation and not temperature [2]. Later studies introduced the combustible cartridge case (CCC), which offer specific advantages over the conventionally metallic brass case. The CCCs are made of cellulose fibers with suitable explosives to ensure debris-free combustion inside the gun barrel. Nevertheless, the presence of explosives in CCC, causes increased vulnerability to cook-off. This phenomenon was studied and addressed by the researchers, R.K. Syal and P.S. Narr, in 1992 and found only 50% of protecting methods gave better results [3].

To compromise between the advantages of metallic and combustible cartridge cases, study was made by the same researchers discussing the design of Brass Obturator of Combustible Cartridge Case for 105 mm Tank Gun Ammunition.

They concluded their study by cutting the defective cartridge case part and replaced by a combustible cartridge part due to deformation occurred in the oral section of the cartridge case [4].

This paper showed that the deformation and cracks were not the only deterioration occurs on the case cartridge, but there is a considerable strength reduction and micro-structural change in terms of phases structure (alloying elements) and grain distribution, size and orientation.

Those changes were addressed using experimental study of tensile strength, microstructural and chemical analysis states before and after firing of brass cartridge case. When comparing the results obtained from before and after states, there are recognizable effects on the performance of the cartridge case.

2. Methodology

Materials and Equipments

Based on "before and after" comparison approach, two groups of samples were prepared, the first group made before firing, (unfired) 60/40 brass cartridge cases with standard mechanical properties for firing; and the second group comprises cartridge cases with the same performance properties after firing, (fired) cases and collected from the range test.

According to American Society for Testing and Materials ASTM standard, the sample groups were further divided and prepared into four subgroups to perform hardness test, tensile strength, microstructure and chemical composition tests. The samples were shown attached with every test method bellow.

3. Methods

3.1. Hardness Test

Using TH600 Brinell hardness device, **Figure 5**, twenty pieces from fired and unfired cartridge cases were tested for Brinell hardness (HB). The brinell hardness testing is suitable for such material (brass) and thickness (1 - 3 mm). The device was set up with 125 kg force, 2.5 mm ball indenter diameter and 15 seconds for loading time. After loading is finished, the average indentations diameters are obtained and then the corresponding HB value is calculated using the tables attached to the device.

3.2. Tensile Strength Test

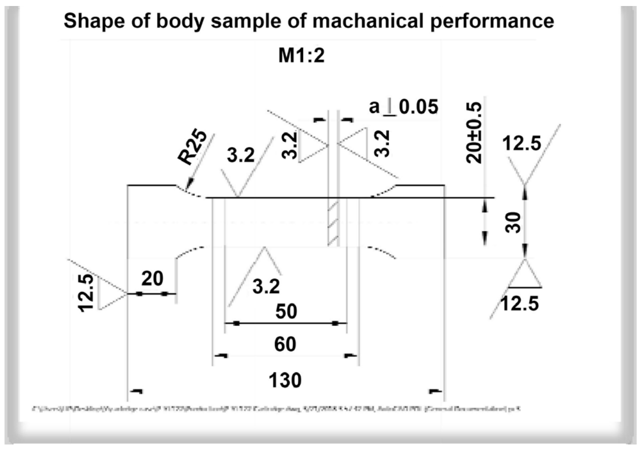
Tensile strength test was performed using a computerized tensile tester and samples prepared as shown in **Figures 6(a)-(d)**. After entering the sample dimensions (width, thickness and cross-section area), the samples were pulled till breaking and the corresponding loads, the tensile strength and graphical representation of the test were directly given by the machine.

3.3. Metallographic Test

Metallographic test was made to investigate the microstructure of samples using

Figure 5. TH600 Brinell hardness test device with the sample mounted.

(a)



(b)

(c)

(d)

Figure 6. (a), BCCoral section for samples; (b), Dimension of tensile strength samples; (c) Tensile strength samples; (d) Tensile strength testing machine.

a Metallographic microscope. The samples were ground, polished and tested according to ASTM B36/B36M-13 standard, which deals with C28000 or Muntz 60% brass. Graphs were captured in X100 magnification, illustrating alloy phases distributions accompanied with grain structure and sizes Figure 7.

3.4. Chemical Composition Analysis

Using chemical analyzer [ESAPORT ANALYTICAL INSTRUMENT-GNR], with two different brass programs (Brass alloy and High alloyed brass), chemical elements in the alloy were tested for the samples before and after firing Figure 8.

4. Results

Hardness test results were obtained according to the Table 1 and Table 2, the hardness of the fired brass case exhibits lower values from those in unfired case, namely (153 - 184) HB in unfired cases and (89 - 103) HB, in fired cases.

4.1. Tensile Strength Results

Results of tensile strength (*TS*) test are shown in Table 3, and graph in Figure 9.

Metallographic test results are represented by tow Metallographic images and tow tables. Figure 10(a), represents image for brass case structure before firing, and Figure 10(b) represents the structure after firing, the images reveal grains, grain contrast for copper and zinc, distribution and sizes of grains.

Table 4 & Table 5 showed the grain size number, G, for brass before and after firing are 9.95 and 11.47, respectively. That means the grains before are bigger than after firing according to grain size and number rule ($N = 2^{G-1}$) [5].

4.2. Chemical Composition Analysis Results

Chemical composition analysis results are shown in Tables 6-8 and Figure 11 below. Firstly six samples were tested using two different brass analysis programs for comparison, which are, *"Brass alloy program" and "High alloyed Brass*

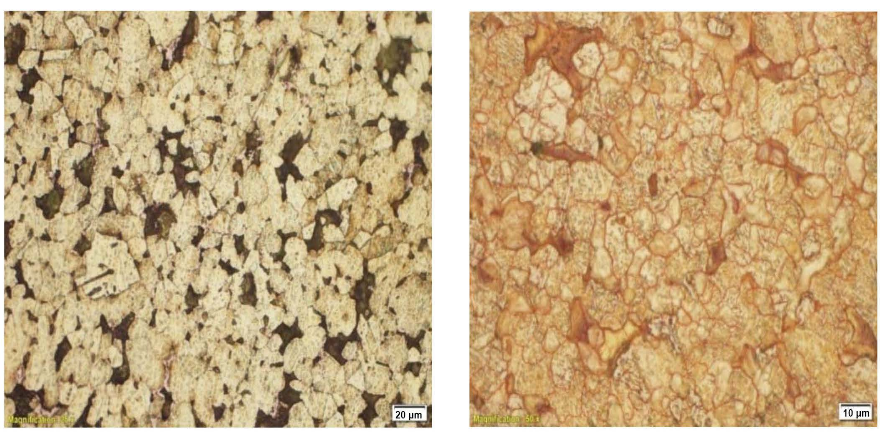


Figure 7. Structure before firing, left and after firing, right.

(a)

(a) (b)

Figure 8 (a) Chemical analysis testing device (Esaport). (b) Chemical analysis test samples, before and after firing.

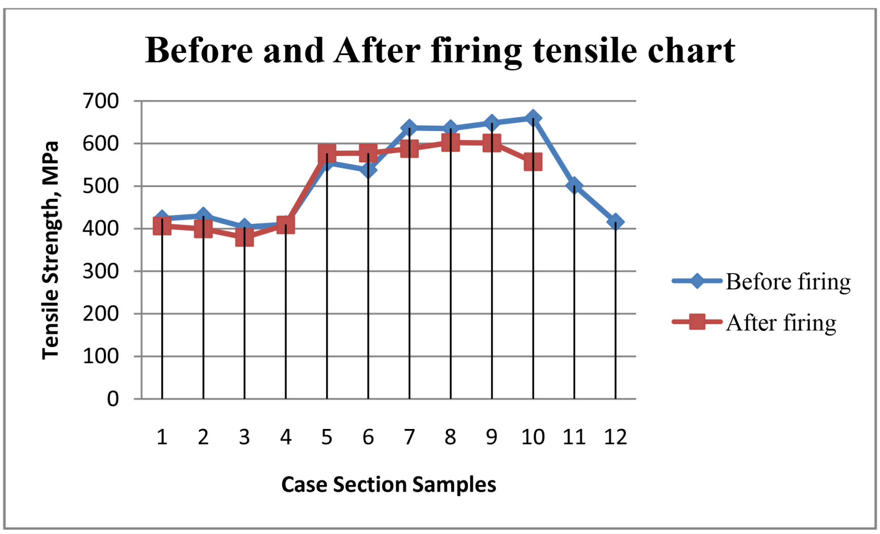
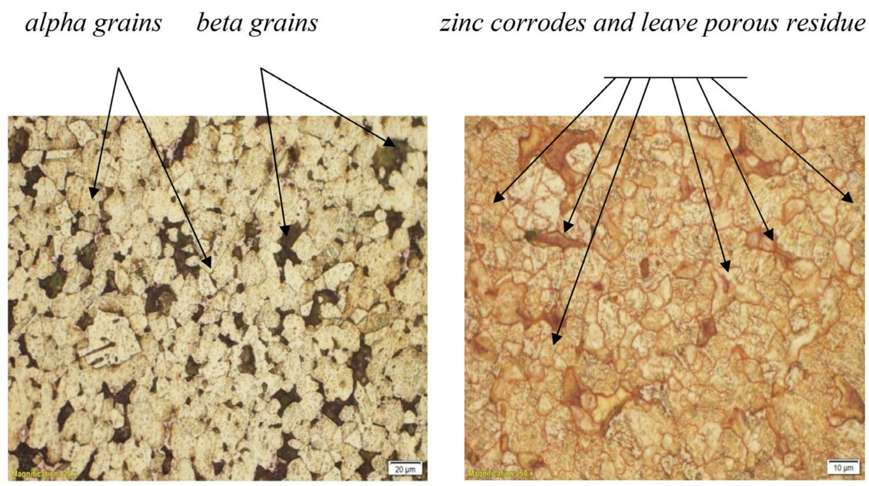


Figure 9. Tensile strength chart for samples before and after firing.

program". In both programs the results showed a notable decrease in the zinc percentage in the brass case after firing, **Table 6** and **Table 7**; and **Figure 11**, although the "brass alloy program" is not accurate to reflect the actual zinc content in the alloy (36% - 39%).



(a) (b)

Figure 10. (a), Structure before firing alpha phase light & beta phase dark, and (b), Structure after firing beta phase lighter & decreased.

Table 1. Hardness obtained from testing unfired cartridge case samples.

Sides	Test samples	Indentation diameter		Average d	Measured HB
		d_1	d_2		
Inner surface	1	1.13	1.125	1.127	177
	2	1.13	1.13	1.13	176
	3	1.14	1.13	1.135	178
	4	1.19	1.19	1.19	158
	5	1.10	1.10	1.10	187
	6	1.21	1.21	1.21	153
Outer surface	1	1.13	1.134	1.132	175
	2	1.133	1.13	1.132	175
	3	1.13	1.13	1.13	176
	4	1.18	1.175	1.178	161
	5	1.11	1.12	1.115	184
	6	1.13	1.13	1.13	176

Table 2. Hardness obtained from testing fired cartridge case samples.

Sides	Test indentation	Indentation diameter		Average	Measured HB
		d1	d2		
Outer surface	1	1.55	1.552	1.55	89
	2	1.448	1.45	1.45	103
	3	1.55	1.55	1.55	89
	4	1.4	1.4	1.4	111
	5	1.4	1.43	1.415	110
	6	1.4	1.4	1.4	111
Inner surface	1	1.55	1.45	1.5	95.5
	2	1.45	1.447	1.449	103
	3	1.44	1.45	1.445	101
	4	1.45	1.45	1.45	103
	5	1.46	1.45	1.455	102
	6	1.45	1.47	1.46	102

Table 3. Tensile strength for samples before and after firing in MPa.

No.	Before & After firing TS	
	Before firing TS	After firing TS
1	423.3	406.2
2	429.9	399.47
3	403.8	379.31
4	409.8	408.81
5	555.2	576.92
6	537.6	577.39
7	636.7	587.9
8	635.2	602.36
9	648.2	601.34
10	659.8	557.09
11	501.3	
12	415.7	

Table 4. Grain size number, G, and number of grains before firing.

A	B
Reference	A1
Group	
Sample Comment	
Date	1/19/2017 2:36:08 PM
Standard	ASTM E 112-12
ASTM Grain Size Number G	**9.95**
Mean Grain Area [μm^2]	130.5
Total Number of Grains	**349**
Total Grain Area [μm^2]	45,545.5
Analyzed Area [μm^2]	59,473.92
Elongation	0.95
Image Number	ASTM Grain Size Number G

Table 5. Grain size number ,G, and number of grains after firing.

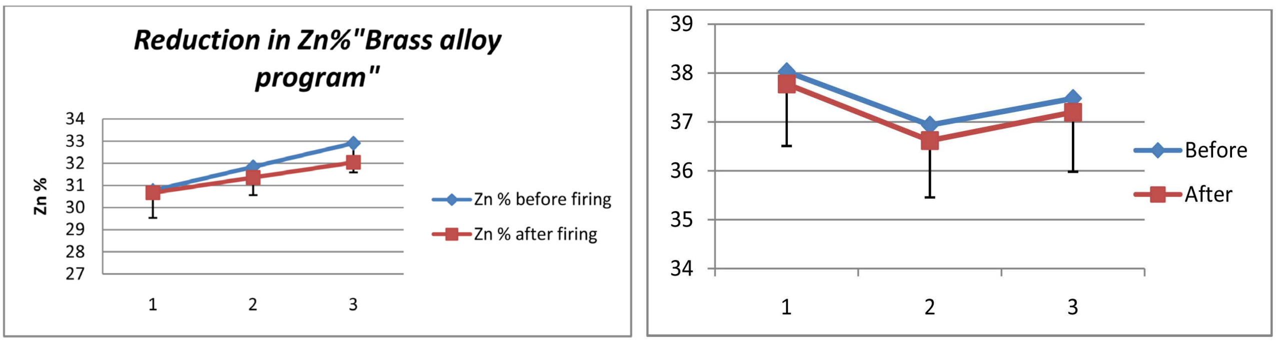
A	B
Reference	A12-G
Group	
Sample Comment	
Date	1/22/2017 10:46:40 AM
Standard	ASTM E 112-12
ASTM Grain Size Number G	**11.47**
Mean Grain Area [μm^2]	45.35
Total Number of Grains	**1141**
Total Grain Area [μm^2]	51,742.16
Analyzed Area [μm^2]	59,473.92
Elongation	0.99
Image Number	ASTM Grain Size Number G

Table 6. Brass alloy program.

	Samples		
Zin% in case before firing (group 1)	A1.1	A1.2	A1.3
	32.907	**30.768**	**31.837**
Zin% in case after firing (group 2)	A2.1	A2.2	A2.3
	32.04	**30.67**	**31.355**

Table 7. High alloyed Brass program.

	Samples		
Zin% in case before firing (group 1)	A1.1	A1.2	A1.3
	38.029	**36.934**	**37.481**
Zin% in case after firing (group 2)	A2.1	A2.2	A2.3
	37.777	**36.619**	**37.198**



(a) (b)

Figure 11. (a) Reduction in Z% by "brass alloy program"; (b) Reduction in Z% by "brass high alloy program".

Finally the "*High alloyed Brass program*" was adopted and demonstrated reduction in zinc after firing by 1% of that before firing. Table 8 and Figure 12 illustrates this result.

5. Discussion

It was seen from the results above, after firing brass cartridge case, there were indications to a reduction in the hardness and the tensile strength accompanied by microstructural disorder and chemical composition change.

According to Table 1 & Table 2 the hardness ranged from (187 to153) HB with an average of 173.3 for unfired decreased to a range from (111 to 95.5) HB with an average of 102 in unfired cases, which is about 40% and the brass became softer. Since hardness is proportional to tensile strength, the results of tensile strength test showed this in Table 3 and Figure 9. The strength decreased from an average of 521.38 to 509.68 Mpa. about 2%. Tensile strength chart in Figure 9, illustrates this reduction especially in the oral and root section of the

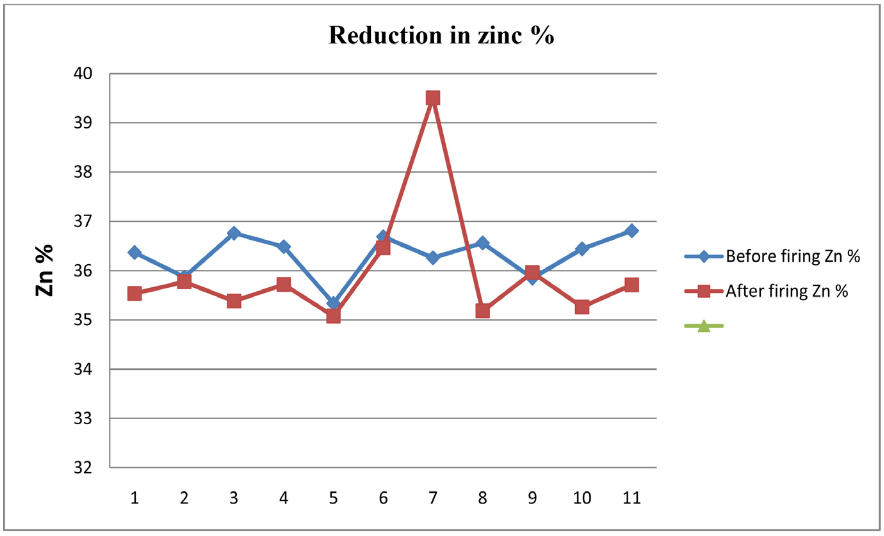


Figure 12. Reduction in Zn % before and after firing "*High alloyed Brass program*".

Table 8. Chemical composition test for fired and unfired cartridge case.

No.	Before firing Zn%	After firing Zn%
1	36.369	35.535
2	35.87	35.773
3	36.761	35.382
4	36.486	35.719
5	35.334	35.076
6	36.689	36.465
7	36.261	39.512
8	36.562	35.182
9	35.847	35.962
10	36.442	35.262
11	36.810	35.712

case which is below the values of unfired case, as shown in Table 9 and Figure 13 by the red color.

In addition to the change of mechanical properties in brass, there was corresponding behavior in the microstructural properties which was revealed in the images Figure 10(a), Figure 10(b), and Table 4 & Table 5. The grains became smaller in size after firing, that is from grain number, G, 9.95 to 11.47 respectively (according to grain size and number rule ($N = 2^{G-1}$) [5], the smaller the G the bigger the grain size and vice versa.).

According to the fact that, softening brass by annealing, grains grow and become bigger; while in this study result the grains became smaller and this may be as a response to the unusual effect of high pressure and temperature of firing.

Also the images (a) & (b) Figure 14 reveals disorder of alpha and beta phases

Table 9. Before and after firing tensile strength (TS).

No.	Before & After firing TS	
	unfired case *TS*	After firing *TS*
1	423.3	406.2
2	429.9	399.47
3	403.8	379.31
4	409.8	408.81

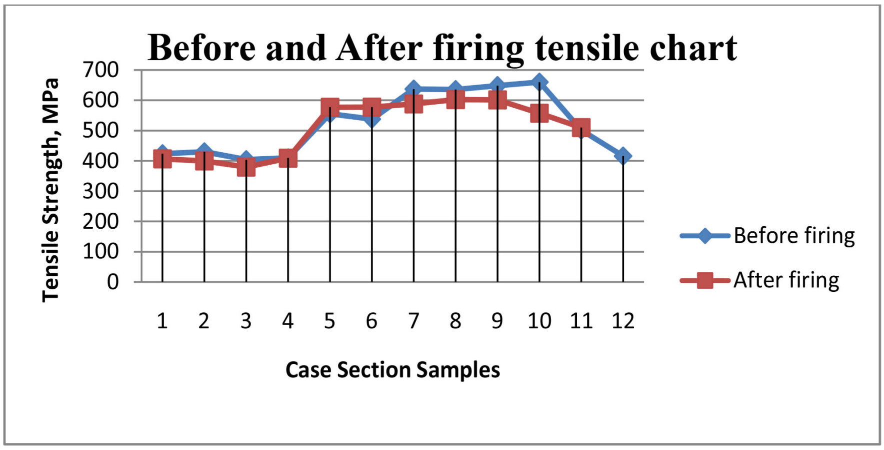
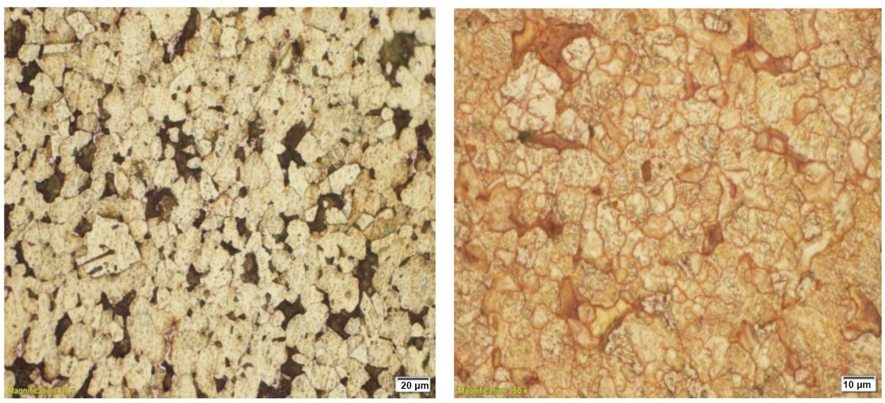


Figure 13. Tensile strength chart for samples before and after firing.



(a) (b)

Figure 14. (a) microstructure before firing; (b) microstructure after firing.

where there is a reduction in the beta phase grains. Part of beta phase has been redistributed in the grain boundaries, Figure 14(a), with the remaining part of the phase less than that in the unfired image. In this situation the alpha phase dominate the structure and the properties of the brass which yield less hardness and strength.

The results from chemical composition showed the deficiency of zinc in the brass after firing as shown in Tables 6-8 and Figure 11(a), Figure 11(b) and Figure 12. Beta phase is mainly composed of zinc element and it is responsible for hardening and strengthening the brass alloy.

According to these findings the structure of the brass case has been remarkably changed after firing in terms of zinc deficiency in the alloy and insertion of beta phase in the grain boundaries. This can be attributed to the mechanism of imposing high temperature and pressure in a very short time of firing. further changes has been encountered in the mechanical performance namely the tensile strength which recorded less values than that of unfired cartridge and this affects any further use of the case.

Former studies justified prohibition of reloading BCC, by presence of cracks due to internal stresses situation described by Dr. Jeno Sipos [1], and the deformation exist after firing which was cured by cutting and replacing with semi combustible cartridge case found by R.K. Syal and P. S. Narr [2].

This study found another reason affecting reloading the brass cartridge case which was analyzed and attributed by the disruption occurred in the structure as described in the above sections.

6. Summary and Conclusions

After firing brass cartridge case, mechanical performance deteriorates which was observed from the test results. The strength decreased after firing by 2%, which limits the reloading. It was due to the distortion occurred in the microstructure of the brass. And this was attributed to the zinc deficiency after firing. The reduction in Zn% was about 1%, between before and after firing samples, (36.31191 and 35.96182) in average.

This deficiency may be attributed to some sort of dezincification happening to brass influenced by the firing conditions. To reload the BCC, strength and structure should be treated and recovered.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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[5] ASTM E112-12, Standard Test Method for Determining Grain Size.

Nomenclature

BCC: Brass Cartridge Case

CCC: Combustible Cartridge Case

HB: Brinell Hardness

TS: Tensile Strength

G: Grain size number

N: Total Surface area of grains