CHARACTERISATION STUDY OF BRASS CARTRIDGES FOR HIGH END COMPETITION TARGET SHOOTING

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Abstract

Reloading of brass 0.308 Winchester cartridges is common in high end target shooting. The work aimed to investigate the effects that successive firing and reloading, procedures have on Lapua manufactured 0.308 cartridge cases. During firing cartridges are exposed to extremely high temperatures and pressures and during reloading, a number of cold work processes are performed on the cartridges. The project was based on the reloading procedure used by Tim Stewart, a member of the British F class rifle team, who proposed and supported the work. The sample sets were designed to study the effects of reloading techniques such as neck turning and cartridge neck annealing. The production of the sample sets required 396 cartridges and 1260 rounds to be fired. Optical microscopy was used to examine cartridge defects and material microstructure. Material hardness was measured using a Vickers Microhardness tester. Residual stress was measured using X-ray diffraction and a scanning electron microscope was used to perform energy dispersive X-ray spectrometry to investigate the chemical analysis of the samples. The neck turning procedure was found to cause cracks to form at the base of the neck. It was suggested that this could be avoided by not neck turning so far down the neck of the cartridge. The research quantified the hardening of the cartridges over 5 firings and 6 reloading preparation procedures. The firing process was found to have a more significant work hardening effect than that of the reloading procedure. The neck turning procedure did not seem to significantly increase the work hardening of the material at the neck of the cartridges. The cartridge neck annealing process was shown to produce variable results. Possible methods of combating the inconsistent annealing results were suggested.

Dissertation word count: 11255

Contents

A copy of the Technical Paper is included at the end of the report.

1.0 List of notations

A	Sample set A
BAA	Sample set B (equivalent to sample set A Annealed)
C	Sample set C
Cu	Copper
C26000	UNS designation for cartridge brass
DCA	Sample set D (equivalent to sample set C Annealed)
EDS	Energy Dispersive X-ray Spectrometry
ft/s	Feet per second
g	grams
grain	Mass measurement used in shooting; roughly equal to 0.065g
grit	Measurement of abrasive grain size used to designate grinding papers
HV	Vickers Hardness Number
LHS	Left Hand Side
ml	Millilitres
mm	Millimetres
ms^{-1}	Metres per second
MPa	Megapascals
PSI	Pound per square inch
RHS	Right Hand Side
SAAMI	Sporting Arms and Ammunition Manufacturers' Institute
SEM	Scanning Electron Microscope
UNS	Unified Numbering System
XRD	X-Ray Diffraction
Zn	Zinc
α	Brass alpha phase
β	Beta phase of brass
µm	Micrometres
°C	Degrees Celsius
0.308	0.308 calibre Winchester type cartridge case
70/30	Brass containing 70% copper and 30% zinc

2.0 Relevant definitions and sample numbering system

Bullet	Projectile released upon firing.
Cartridge base	Primer end of the cartridge.
Cartridge body	Middle part of the cartridge by length.
Cartridge case	Case that holds bullet, primer and propellant.
Cartridge neck	The end of the cartridge in which the bullet is seated.
Cartridge shoulder	The angled part of the cartridge.
Firing-reloading cycle	Shooting and then reloading of a cartridge case.
Prep	Procedures to prepare a cartridge for loading
Primer	The charge designed to ignite the propellant upon firing.
Primer pocket	The part of the cartridge into which a primer is inserted.
Round	A fully loaded cartridge, bullet, primer and propellant configuration.
Sample set	A set of cartridges from different stages that form successive firing-reloading cycles.
Seating	To force a bullet into the neck of a cartridge.
Stage	A subset of the sample set which defines what point the cartridge is at in the preparation/firing sequence.
Unseating	To remove a bullet from a cartridge.

2.1 Sample numbering system:

Numbering system to define individual cartridge samples (Please refer to table 1; section 5.0).

Sample set – stage number – cartridge number from set

For example: Cartridge *BAA-7-1* refers to cartridge 1 from stage 7 (prep 4) from sample set BAA (equivalent to sample set A but with annealing steps i.e: A-Annealed)

3.0 Introduction and background

The reloading of brass cartridge cases is common in sports shooting. The reloading process is usually undertaken to achieve a monetary saving but can be used to improve accuracy; such as in high end competition shooting.

The cost effectiveness of reloading can easily be seen when the price of brass cartridges are taken into consideration; 0.308 cartridge cases generally cost between £0.30 and £0.60 depending on the manufacturer and distributor[1]. The improvement of accuracy by reloading is achieved through the tailoring of the round to the individual shooter's needs and rifle. By undertaking a reloading process, a shooter can control powder quantity and quality; bullet size and seating depth; and primer type.

There are no prescribed optimum conditions for the loading of a brass cartridge case and the reloading technique used can vary from shooter to shooter. To maintain accuracy a shooter must ensure that his/her rounds are as consistent as possible. When at the range; a shooter will use the first two or three rounds as sighting shots to set up their rife and sight to suit the performance of the rounds and ambient conditions. If the consistency of a batch of rounds is high then the performance of each round should be the same; thus the variation over a number of firings should only be caused by the shooter or weather conditions. Consequently the ultimate aim of a reloader is not to achieve a single 'perfect' round but to achieve the highest levels of consistency between each round in a batch of reloaded cartridges. The performance characteristics of each batch may differ but the accuracy of the shots should be maintained as long as the shooter adjusts the sight of the rifle to suit every batch.

In a reloading process brass cartridge cases are generally purchased from a dealer in an unloaded condition. The basic cartridge case loading process involves[2]:

- Cleaning the case

- Case inspection and disposal of cases with defects
- Lubrication of the case (for sizing process)
- Case sizing
- Case priming
- Charging the case with propellant (loading the powder)
- Seating the bullet in the case

Some types of bullets also require a crimping process to be performed. Many shooters add 'extra' stages to their loading process to suit their specific needs or to try to increase the consistency of the performance of a batch of cases. Once a round has been fired the cartridge case is saved for reloading. A fired cartridge is de-primed to remove the spent primer from the case; then the case can be reloaded following the steps described above.

A single cartridge can be reloaded and fired numerous times throughout its lifespan. The number of times that a case is reused is dependent on the individual shooter. Some shooters reload cartridges a specific number of times then discard the cases whilst others reload their cases until there are visible signs of defects. The lifespan of a case is dependent on the case type, manufacturer and the conditions that the cartridge is exposed to throughout its life. In general, many shooters can achieve between 5 and 20 reloads for each cartridge. Many reloaders try to expand the lifespan of their cartridges by including an annealing process in some of their firing-reloading cycles.

Cartridge case neck annealing is widespread throughout the sport. Despite this, the method and frequency in which annealing is undertaken varies between shooters. Most processes that are in use employ a propane gas burner to produce the high temperatures needed for the heat treatment. Some of the variations to the process include: turning the cartridge in the flame; motorised cartridge holders to move the cartridge through the flame and heating the cartridge in a shallow tub of water to

ensure the base is not affected by the heat. Shooters also vary in their use of cooling techniques and the time and temperature at which they heat to.

Despite the large number of reloaders and variation in reloading method there seems to be little research into the effects that a number of firing-reloading cycles can have on a brass cartridge case. The project aimed to provide some insight into the effects that a typical reloading procedure, used in high end competition target shooting, has on brass cartridge cases.

3.1 Background to the project

The investigation was proposed by Tim Stewart; a member of the British F class rifle team. The study was based on the reloading procedure used by Tim Stewart and was designed to investigate the effects that a number of firing-reloading cycles have on a brass cartridge case. Tim Stewart supported and helped to fund the project by supplying the cartridges and undertaking the reloading and firing processes that were needed to produce the sample sets examined in the project. The consumables used to produce the rounds; such as bullets, primers and propellant; were also supplied by Tim Stewart. When in competition Tim Stewart generally shoots at 1000 yards although, as the shooting distance does not alter the effects of firing on the cartridge, the shooting for the project was completed at 200 yards.

The work focused on the 0.308 Winchester cartridge type and solely considered cartridges manufactured by Lapua. In the shooting world Lapua are considered to be one of the top manufacturers of brass cartridge cases and are the manufacturer of choice for Tim Stewart when in competition. Although Lapua cartridge cases are typically more expensive than competing brands; this was seen as a necessary expense to make the findings of the project directly applicable to the competition shooting undertaken by Tim Stewart. Figures 1 and 2 show an unfired Lapua cartridge and a Lapua cartridge after 5 firings respectively.

Figure 1 – Unfired Lapua 0.308 cartridge case

Figure 2 – 0.308 Lapua cartridge case after 5 firings

0.308 cartridge cases are generally produced from 'cartridge' brass (70% Cu and 30% Zn)[2]; UNS designation C26000. No detailed information could be found on the chemical composition of the brass used by Lapua in the manufacture of their cases. An email sent to the Lapua, detailing the project and asking for supporting information, did not receive any reply. In the absence of this information the composition of the cartridge cases was assumed to conform to the ASTM International Standard Specification for Cartridge Brass cartridge Case Cups[3]. This gives the acceptable copper content as 68.5-71.5%; the maximum content of impurities such as lead, iron and bismuth as 0.07%, 0.05% and 0.006% respectively; and zinc as the remainder of the chemical composition[3].

The manufacture of a cartridge case involves a number of cold work processes such as cupping, drawing and indenting and also includes annealing processes to release stresses in the cartridge[4]. Throughout its lifespan a cartridge is exposed to extreme

temperature and pressures during firing and must withstand cold work processes used to prepare the cartridge for loading. During firing, a cartridge can be exposed to pressures as high as 427MPa (62,000PSI[5]) and temperatures of around 200°C[6]. Although the cartridge is only exposed to these extreme conditions for a very short period of time; the firing procedure causes the cartridge to work harden. As it is the cartridge that holds the bullet in place; differences in the properties of the brass can affect the exit velocity of the bullet from the cartridge. This can have serious effects on accuracy as at 1000 yards (914.4m) a change in velocity of 10ft/s (roughly $3ms^{-1}$) can cause a shot deviation of a few inches at the target[7]. This magnitude of deviation could mean the difference between a first and a last place at a competition.

The large potential influence of cartridge properties on shooting accuracy formed the underlying reason for undertaking the project. The project aimed to characterise the material properties of 0.308 Lapua cartridges over successive firing-reloading cycles. In addition; the project aimed to investigate the effects of cartridge neck turning and cartridge neck annealing which are two processes used by Tim Stewart in the preparation of his cartridges for firing.

4.0 Literature review

As described in section 3.1 the work was to focus on the reloading methods used by Tim Stewart. Throughout the project the information provided by Tim Stewart was complemented with information from forums, books, technical standards and journals.

A review of shooting internet forums and shooting websites revealed that most shooters use slight variations of the same process for reloading their cartridges. The basic reloading process, detailed in section 3.0, was described on many websites such as the RCBS reloading guide[8] and followed the same steps as described in the Speer Reloading Manual[2]. The research into reloading methods revealed that many shooters include variations in the reloading process to suit their needs and preferences. One such variation is a polishing step, in which cartridge cases are polished for 3 hours using a case tumbler, described on the website 'Rifles in the UK'[9]. Another variation is the cartridge neck turning procedure; used by Tim Stewart (see section 5.2) and described on the website: '6mmBR.com'[10]. The conclusion drawn from the varied information presented in a number of websites and blogs is that there is no 'best practice' method for reloading cartridges and that many reloaders base their procedure on experience or their personal preferences.

As explained in section 3.1 no detailed information on the chemical composition of the Lapua brass was found. The Speer Reloading Manual[2] did suggest that the chemical composition was likely to be around 70% copper and 30% zinc. Due to this the composition was assumed to adhere to the ASTM International standard[3]; the details of which have already been described in section 3.1. Information on the properties of C26000 or 'cartridge brass' was found in the ASM Materials Handbook; Volume 2 [11].

The dimensions of the 0.308 Winchester type cartridge cases were found to be specified by the Sporting Arms and Ammunition Manufacturers' Institute SAAMI. The specified dimensions of such a cartridge are shown below.

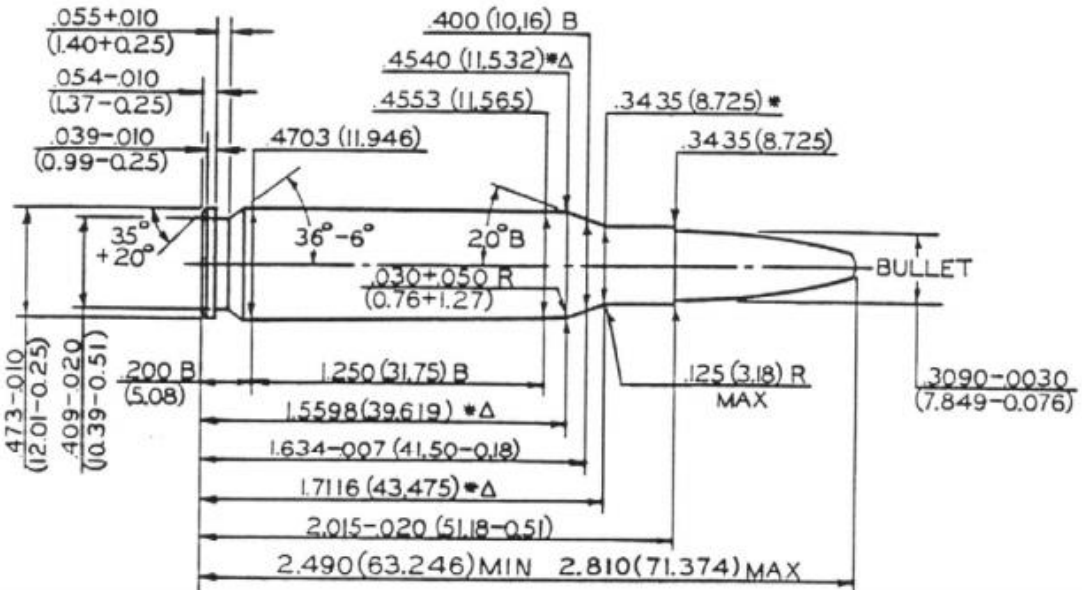

Figure 3 – Specified dimensions of a 0.308 Winchester type cartridge [12]

The use and application of cartridge case annealing, also appears to be based largely on individual shooter preference. The Speer Reloading Manual[2] did not provide any information on cartridge neck annealing however there was much discussion of its use over internet forums and shooting websites. Some shooters don't practice cartridge neck annealing while others, who seem to be more committed to preserving their brass, disagree on the frequency and method of annealing. Some shooters such as Rich DeSimone anneal cartridges after every shot when preparing rounds to be fired at 1000 yards[13]. This differs from the frequency undertaken by Tim Stewart who usually performs a first cartridge anneal after three shots; thereafter increasing the annealing frequency to after every second firing (see section 5.3). The annealing methods also seem to vary, with some shooters utilising mechanised turntables to move the cartridge through the flame of a gas burner[13]. Others use electric drills to turn cartridges in the flame of a gas burner and some position the cartridges in a pan of water and manually apply the fame of a burner to try to protect the lower part of the cartridge case[13] . There was also reference to the use of molten lead to anneal the neck of the cartridge cases but this seems to be an older method that is not widely used today[13]. Most sites advised the use of temperature indicators such as Tempilaq[14] but the advice on

annealing temperature and time was quite variable. In common with the reloading procedure, the annealing methods in use seem to be based on the personal preference of the shooter in question. It could also be argued that the annealing procedures in use were relatively crude in that there was little ability to accurately control the annealing temperature or time. There was no evidence to suggest that the annealing methods had been researched to determine an optimum application time.

Internet research also provided information on the manufacture of cartridge cases which involves a number of cupping, drawing, indenting, and trimming processes[15]. It also described how annealing stages have been introduced in to the manufacturing process of brass cartridges to relieve material stresses and combat 'season cracking' [4].

The paper by Verma et al[16] focused on the effect of cold work procedures on the grain size and strength of cartridge brass. The process of work hardening was explained using the Taylor Model in Chapter 11 of Modern Physical Metallurgy[17]. This model describes work hardening as the interaction of crystal dislocations under flow. As two dislocations meet they become 'stuck' and hence obstruct the motion of other dislocations. This in turn impedes the flow of the material and thus the material hardens. Work hardening can be used to describe the effects that the cold work processes, used in the manufacturing process of cartridge cases, have on the material properties of the brass.

The paper by Sachs, Espey and Clark on 'Factors Influencing the Stress Cracking of Brass Cartridge Cases'[18] provided information on how the stress introduced during manufacture could cause cartridge cases to crack. The paper on 'Residual Stress in Caliber 0.30 Cartridge Cases' by Rosenthal and Mazia[19] investigated the residual stresses in 0.30 cartridge cases under different annealing conditions. This study established that the stresses at the neck of the cartridge were larger in the longitudinal direction than in the circumferential direction while at all other points in the cartridge the longitudinal stress was negligible. These two papers were

published as part of a Symposium on Stress-Corrosion Cracking in 1945. The time of writing coincides with the end of the Second World War which may explain the large volume of work regarding cartridge cases produced around this time.

The work of David Saunders, for the Australian Department of Defence, on low temperature annealing of 7.62mm cartridge cases[20] described how low temperature annealing of brass can cause increases in hardness. Saunders demonstrated how the neck annealing procedure, used in the manufacturing stages of brass cartridges, can cause the lower parts of the cartridge to be low temperature annealed and thus hardened. It was shown that this effect did not cause any significant increase in stress-corrosion susceptibility. This is notable when considering the effect of the cartridge neck annealing procedures employed by reloaders (as described above).

Reference to Modern Physical Metallurgy by Smallman and Ngan[17] provided information on the process of annealing and the phase diagram of a copper-zinc system (shown below).

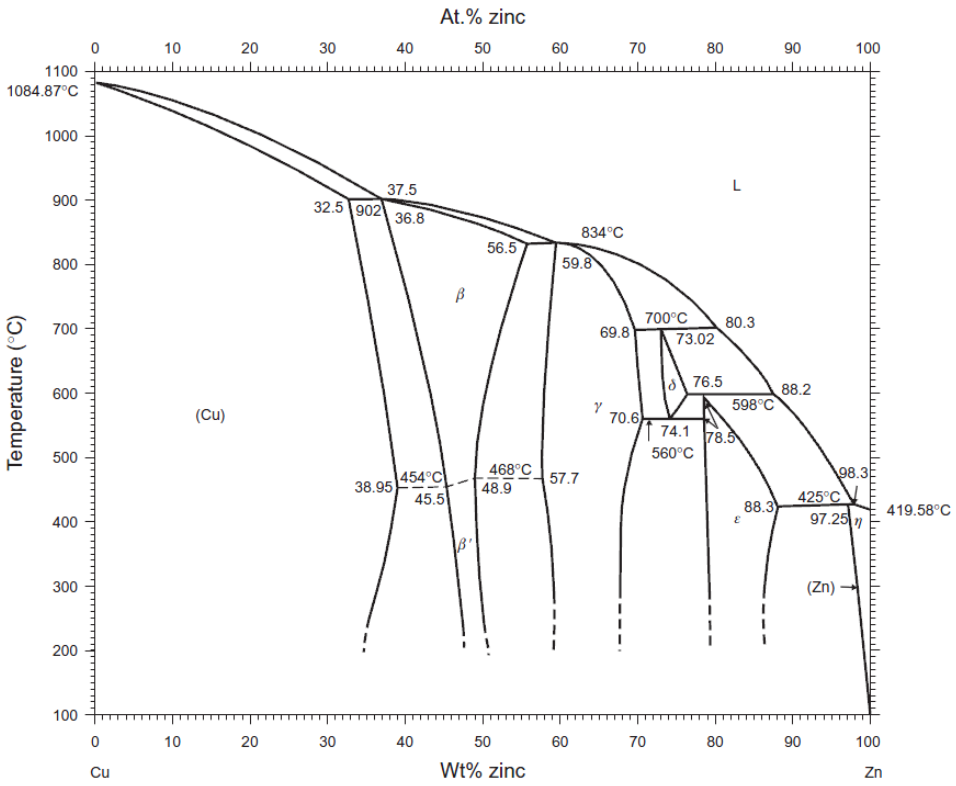

Figure 4 – Phase diagram of a copper-zinc system[17]

From the diagram it can be seen that cartridge brass (70Cu/30Zn) is predominantly in the α or 'Cu' phase. The ASM Materials Handbook[11] also states that cartridge brass only very rarely exhibits a β phase due to segregation. This suggests that the properties of the cartridge brass after annealing should only depend on the starting conditions and the temperature and time of the heating process.

It is interesting to note that in their investigation into the effects of process annealing on microstructure and texture of cartridge brass; Hagos et al[21] suggest that process annealing of cartridge brass has better results if an intermediate annealing process is carried out at low work conditions. This has little relevance to the annealing process employed by some shooters as the majority of the cold work procedures are carried out during manufacture of the cartridge cases. Despite this, it can be seen that the variation of the initial condition of the brass will have significant results on the end properties produced by an annealing process.

Research was carried out into potential methods of characterisation of the cartridges to be examined during the work. In their examination of Remington rifle brass cartridges from the La Verde battle site Pichipil et al[22], made use of optical microscopy, SEM microscopy and X-Ray Energy Dispersive Spectrometry (EDS). These techniques allowed examination of the material microstructure and chemical characterisation of the brass used in the production of the cartridges. In his work David Saunders[20] also unsuccessfully tried to measure residual stress in 7.62mm cartridges using X-ray diffraction. More information on the XRD residual stress measurement technique was found in the guide produced by the National Physical Laboratory[23].

A large amount of information regarding propellant quantities and corresponding bullet exit velocities was detailed in the Speer reloading manual[2]. This was not considered to be particularly relevant as the project scope did not involve varying the quantity or type of propellant in use.

The literature review carried out during the project showed that, although much is known about the properties of cartridge brass and optimum methods of producing cartridge cases; little research has been done into the effects of reloading brass cartridges. It could be assumed that this is one reason why the reloading method employed has been seen to vary slightly from shooter to shooter.

5.0 Reloading procedure and sample sets

As mentioned in section 3.1 the main aims of the project were to investigate the following:

- The effects of successive firing and reloading processes on the properties of 0.308 Lapua cartridge cases.
- The effects of neck turning on cartridge cases.
- The effects of cartridge neck annealing.

To produce this study it was necessary to define suitable sample sets and consistent reloading procedures. The sample sets and cartridges in each are shown in table 1.

Stage	Stage No.	Sample Set A	Sample Set BAA	Sample Set C	Sample Set DCA
Factory	0	20			
Prep 1	1	10		10	
Fire 1	2	10		10	
Prep 2	3	10		10	
Fire 2	4	10		10	
Prep 3	5	10		10	
Fire 3	6	10		10	
B and D Anneal	A1		10		10
Prep 4	7	10	10	10	10
Fire 4	8	10	10	10	10
Prep 5	9	10	10	10	10
Fire 5	10	10	10	10	10
Prep 6	11	10	10	10	10*
Anneal	12	10	10	10	6
TOTAL CARTRIDGES		**396**			

Table 1 – Cartridge sample sets and stages within each set

*Sample set D, stage 11 not prepped for reloading so equivalent to set D stage 10

In mind of the aims of the project two main sample sets and two subsets were created. The two main sample sets were composed of cartridges at consecutive stages of reloading and firing and were labelled sets A and C. Both sets were treated the same way except that set A was not neck turned at the first preparation stage while set C was (see section 5.2 for a description of cartridge neck turning).

These sets were designed to produce data on how successive firing-reloading cycles affect the cartridges and if neck turning causes any significant variation to the cartridge behaviour throughout these cycles. To do this both sets included a number of stages.

Stage 0 was common to both sample sets in that it contained cartridges as purchased from the manufacturer (as exported by the factory). The following stages were consecutive ‘prep’ and ‘fire’ stages. The ‘prep’ stages contained cartridges that had gone through the preparation procedure for reloading but had not been loaded. In this way these cartridges had undergone all the cold work processes that a cartridge would during a reloading process. The ‘fire’ stages contained cartridges after a firing procedure. The examination of cartridges at ‘prep’ and ‘fire’ stages allowed the investigation to examine the effects of a case preparation procedure and a firing procedure separately. Enough stages were included in the sample sets to examine the cumulative effects of successive preparation and firing up to a sixth preparation stage (just after the fifth firing). A final annealing stage was added to each set (stage 12) to examine the effects of cartridge neck annealing (see section 5.3 for a description of the annealing process used).

To further investigate the effects of annealing two sample subsets were created. These were sets BAA (set A Annealed) and DCA (set C Annealed). As their names suggest sets BAA and DCA were equivalent to sets A and C respectively; the only difference being that an annealing procedure was performed on each subset after the third firing (fire 3). As the subsets were equivalent to their parent set up to just after the third firing there was no need to produce stages 1 to 6 in the subsets.

The production of the sample sets required 396 cartridges and a total of 1260 rounds to be loaded and fired. A task that was undertaken early in the project was to define the reloading and firing procedures that the samples would be subjected to.

5.1 Reloading procedure

The reloading procedure was split into two processes – the preparation process and the loading process.

The preparation process contained all of the cold work procedures used to prepare the cartridges for loading and it was after this process that the cartridges were included in the 'prep' stages. The steps involved in the preparation process are described in table 2.

Preparation Steps		Description	Sample Sets A and BAA	Sample Sets C and DCA
1	Full length resize	Resize the case to specified dimensions using press and sizing die.	√	√
2	Flash hole uniform	Ensure that flash hole is uniform in size using flash hole uniform tool.	√	√
3	Primer pocket uniform	Ensure that the primer pocket is uniform in size and depth using primer pocket uniform tool.	√	√
4	Trim to uniform length	Ensure case is correct length using case trimming tool.	√	√
5	Chamfer outside	Very slight chamfer using cartridge chamfering tool (outside).	√	√
6	Light chamfer inside	Very slight chamfer using inside chamfering tool. This helps to ensure easy bullet seating.	√	√
7	Mandrel neck expand	Ensure that the neck of the case is the correct size using press and expander die.	√	√
8	Neck turn	Use neck turning tool to trim the neck of the cartridge to ensure a circumferentially uniform neck thickness.		√
9	Chamfer and polish	A further chamfer to remove any burrs caused by neck turning, then polish with a cloth.		√
10	Polish outside neck	Polish with a cloth.		√
11	Resize bushing (as required)	Use bushing die to accurately resize the neck of cartridges that require it.	√	

Table 2 – Sample set preparation procedure[24]

It must be noted that steps 8 to 11 were only performed during the first preparation stage (prep 1). These are the steps associated with neck turning (steps 8 to 10) and the step that may have to be performed on some cartridges if neck turning is not carried out (step 11). The process of neck turning is more fully discussed in section 5.2.

The steps undertaken to complete the loading process are described in table 3. This process was used to load the cartridges from all of the sample sets.

Loading Steps		Description
1	Case sorting	Weigh every case and arrange into batches of mass variation of 0.5 grains. This is done to ensure that the cartridges in each batch have negligible variation in mass. Lapua cartridges usually are within a mass range of 171.0-174.9 grains.
2	Bullet sorting	Weigh bullets and batch into groups of 1.0 grain or 0.2 grain variation depending on the recorded masses. All bullets should be within a 2 grain range of the stated 196 grains. The bullets are batched to ensure that each batch is as homogeneous as possible so as little compensation as possible is needed when firing.
3	Case priming	Seat primer in cartridge cases.
4	Powder throwing	Use powder thrower to 'throw' 44.5 grains of powder (propellant). Use optically controlled powder trickler to take powder up to a mass of 46.0 grains. Use lab scale and tweezers to ensure that mass of powder is within a tolerance of 46.0+0.02-0.0 grains.
5	Case charging	Put propellant into cartridge using a funnel. Lightly place a bullet into the neck of the cartridge to show that cartridge has been charged.
6	Bullet seating	Press bullet into case to the seating depth (use Arbour press & chamber fit die for minimal force). Lightly clean the case with a cloth and mark the batch number onto the cartridge.

Table 3 – Cartridge loading procedure[24]

Please note: a 'grain' is a mass measurement used in shooting procedures and is roughly equivalent to 0.065g

When the cartridges are fully loaded (as rounds) they are stored securely until required for firing. Throughout the project the rounds were fired at a target distance of 200 yards as mentioned in section 3.1.

After firing, all cases were de-primed to remove the spent primer from the cartridge and cleaned using a sonic cleaner. Cartridges that were to be reloaded were again taken through the preparation process.

All cartridge samples were cleaned using a sonic cleaner before being included in the relevant sample set. This was done to ensure that residue left on the inside of the cartridges during firing was removed before experimentation.

5.2 Cartridge neck turning

As described in table 2 cartridge neck turning is a process used to ensure that the wall thickness of the cartridge neck is uniform. This procedure uses a tool to trim down the thickest parts of the outside wall of the cartridge neck.

The bullet is held in place by the neck of the cartridge. The force that the cartridge neck applies to the bullet is referred to as the 'neck tension'. It is believed that ensuring the wall thickness of the cartridge neck is uniform should ensure that the 'neck tension', which the cartridge applies to the bullet, is uniform about the circumference of the bullet. This is thought to be important to allow the bullet to leave the cartridge as smoothly as possible upon firing.

The process of neck turning is used by many competition shooters; including Tim Stewart. The study was designed to investigate whether the neck turning procedure has any effects on the properties of the cartridges during successive firing-reloading cycles.

5.3 Cartridge neck annealing

The cartridge neck annealing process used by Tim Stewart is described in table 4. This process is usually first applied to the cartridges after they have been fired three times and then the cartridges are re-annealed after every two firings[24].

Annealing Steps	Description
1	Prepare 5 calibration cases with Tempilaq yellow (A solution used to indicate a temperature of 750°C)
2	Place first calibration case in a case holder attached to a cordless electric drill.
3	Turn case by powering up drill.
4	Heat case by applying the flame of a propane gas burner to the neck of the turning case.
5	Measure the time to reach the annealing temperature as indicated by the Tempilaq.
6	Repeat procedure for other calibration cases and calculate average annealing time.
7	Anneal all other cases as from step 2 to the annealing time calculated using the calibration cases.
8	After all cases have been annealed ensure cases have cooled by dipping in cold water
9	Blow dry cases (blow water out of cases with compressed air).

Table 4 – Cartridge neck annealing procedure[24]

Although the annealing process used by Tim Stewart could be described as fairly crude it seems to be in common use by reloaders throughout the world. It was decided it was important to include an investigation into the effectiveness of the annealing process in the project.

6.0 Un-etched microscopy

The first experimental procedure performed during the work was to examine a longitudinal cross section of the cartridge samples using an optical microscope. This required the cartridges to be set in an epoxy resin then ground and polished. These resin samples would be used for further experimental procedures after the microscopic examination.

The cartridges that were prepared in resin for the experimental procedure are detailed in table 5.

Stage	Stage No.	Sample Set A	Sample Set BAA	Sample Set C	Sample Set DCA
Factory	0	5			
Prep 1	1	3		3	
Fire 1	2	3		3	
Prep 2	3	3		3	
Fire 2	4	3		3	
Prep 3	5	3		3	
Fire 3	6	3		3	
B and D Anneal	A1		3		3
Prep 4	7	3	3	3	3
Fire 4	8	3	3	3	3
Prep 5	9	3	3	3	3
Fire 5	10	3	3	3	3
Prep 6	11	3	3	3	3*
Anneal	12	3	3	3	3
TOTAL CARTRIDGES		**119**			

Table 5 – Cartridges prepared as resin samples

*Sample set D, stage 11 not prepped for reloading so equivalent to set D stage 10

6.1 Experimental Procedure

Five samples from the factory stage and three samples from each stage thereafter were prepared for examination. A fully polished cartridge-resin sample is shown in figure 5.

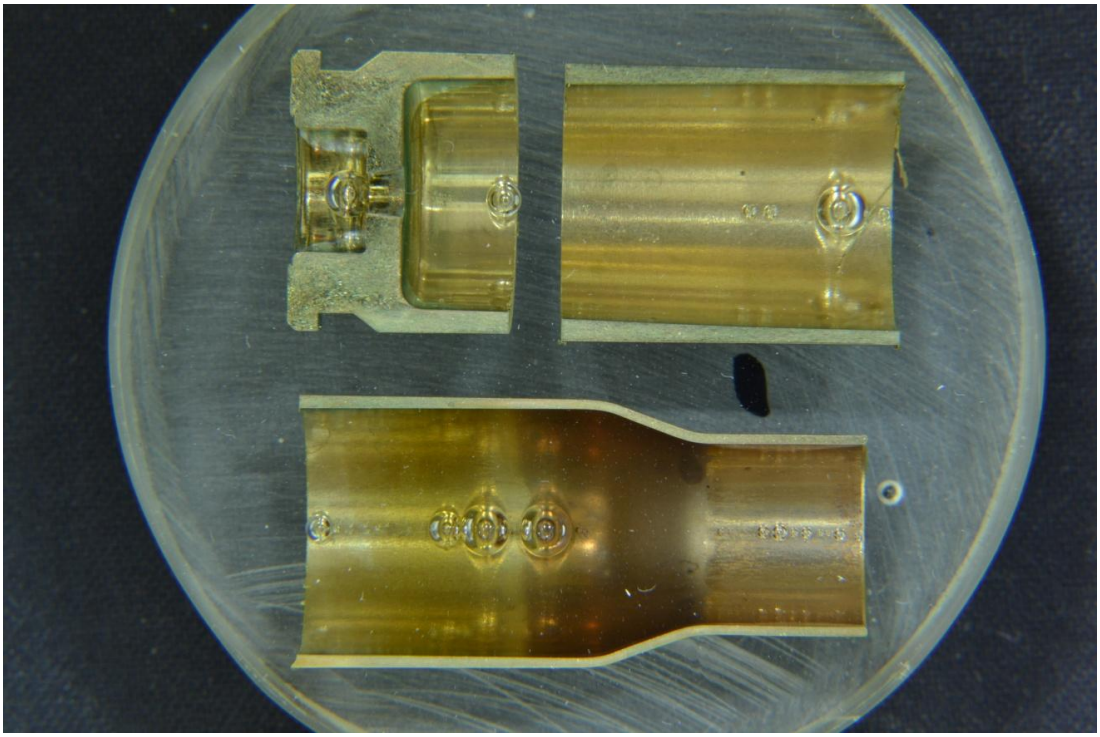

Figure 5 – Photograph of cartridge sample mounted in epoxy resin

To prepare the cartridges for examination they were first cut up. The cartridges were cut into three sections by length. The first cut was made at a position 25mm from the neck of the cartridge and the other cut was made at a position 10mm from the base of the cartridge. Due to the large number of cartridge samples to be prepared, these cuts were made using a Struers Discotom circular saw. This meant that the cuts could only be ensured to be at the rough position as described above. The blade diameter of the saw also meant that roughly 2mm of the cartridge was lost at the cutting position. The cuts were made to ensure that the cartridge samples fitted into a 40mm sample pot and to make it easier for the air to escape from the inside of the cartridge samples when setting in epoxy resin.

After the samples were cut up they were cleaned using warm soapy water in order to degrease them, before setting in resin. Initially the three pieces of each cartridge sample were glued onto card disks to provide the spacing as shown in figure 5. This process was changed after the first 35 samples were set in resin as it was found that the card disk introduced air bubbles into the resin. To achieve a similar layout for

the other cartridge samples; double sided sticky tape was used to secure the pieces of each sample within the sample pot.

The sides of the sample pots were lubricated with silicone oil to aid the release of the sample after solidification. The cartridge samples were secured within the pot (by card or tape method) and then the epoxy resin was used to fill the sample pot. The resin used was 'Struers Epofix' epoxy resin and had to be mixed with a hardener before it would solidify. After the resin had been added; the samples were left to solidify in a hotbox (a small air heater with a surrounding box to hold the samples).

When dry the samples were removed from the pots and were marked with the designation system as described in section 2.1. The samples were ground to a longitudinal half section using a silicon carbide grinding paper with a grain size of 120grit. The grinding was done by mounting the samples in a sample holder (which could hold 6 samples) and then inserting the holder into a Rotoforce-4 semi automatic specimen mover attached to a Struers Rotopol-21 grinding machine.

After the samples had been ground to a half section using 120grit grinding papers they were ground for a short period of time on 220grit, 500grit, 800grit, 1200grit and 2000grit papers. This was done to prepare the samples for polishing.

To polish the samples a different type of sample holder was used. This allowed the samples to be removed individually when polished or for cleaning purposes but only held a maximum of three samples. The samples were polished using polishing disks with an abrasive grain size of 6µm then 3µm and corresponding diamond polishing suspensions. The final polish was achieved using a polishing disk with an abrasive grain size of less than 1 µm and a silica oxide polishing solution.

The samples were examined using an optical microscope.

6.2 Results and discussion

Microscopic examination of the samples showed some minor impurities contained within the brass and some small areas of corrosion. These features are shown in figures 6 and 7 respectively.

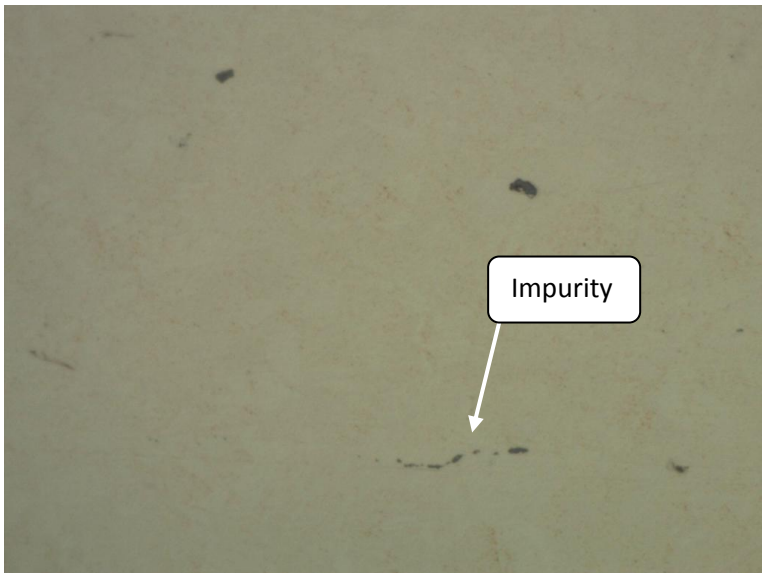

Figure 6 – Neck impurities in sample 0-1 (1000 times magnification)

The impurity shown in figure 6 was found at the neck section of the cartridge. It appears to have been elongated which suggests that it was present in the brass before it was drawn to produce the cartridge. Figure 6 is a highly magnified image (at 1000 times magnification) and it is likely that small impurities such as this will have no significant effects of the performance of the cartridge.

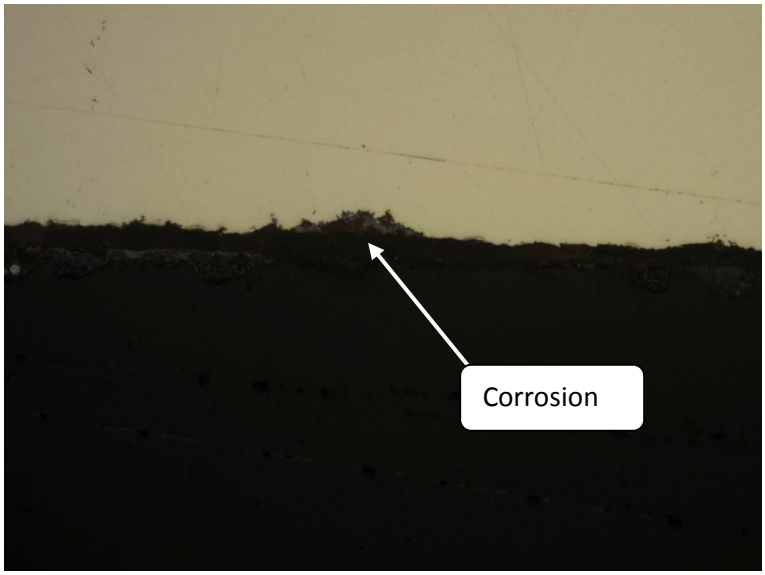

Figure 7 – Corrosion on inner wall at mid-section of sample DCA-A1-3 (500 times magnification)

The corrosion shown in figure 7 was found on the inside wall of a cartridge from sample set DCA, which had just been annealed. Such examples of corrosion were found on a few cartridges, especially cartridges within the higher stages of each sample set. No significant amounts of corrosion were found; suggesting that corrosion should not be a problem in well cared for cartridges.

The microscopic examination did find a few cases of cracks present in the cartridge samples. One such crack was found at the corner of the inside of the cartridge base. This crack was observed in all samples. In the factory stage samples this crack was present but was very thin. Throughout the firing-reloading cycles the crack opened up but did not seem to propagate. Figures 8 and 9 show the crack in a factory stage sample and in a cartridge from sample set A at prep stage 6 respectively.

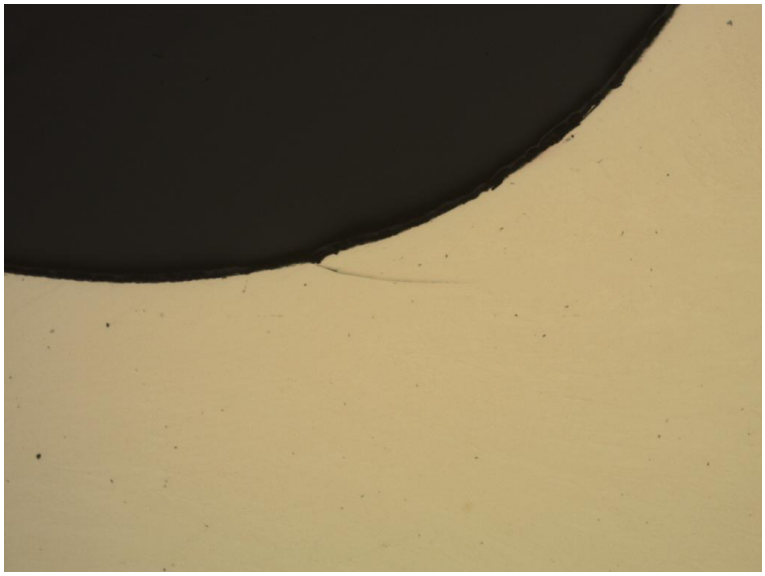

Figure 8 – Crack at inside of base in sample 0-1 (50 times magnification)
Cartridge in horizontal position

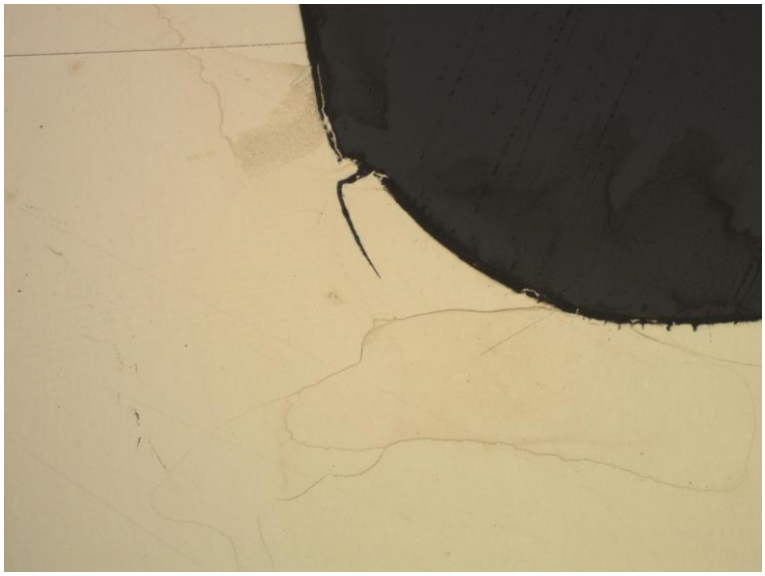

Figure 9 – Crack at inside of base in sample A-6-1 (50 times magnification) Cartridge in vertical position

The figures show the crack before and after use of the cartridge. As the crack is present in the factory stage cases it is likely that it is a product of the manufacturing process. The position at which it is present will act as a stress raiser but the cartridge wall thickness at this point is large. The crack does not elongate upon use of the cartridge and is not likely to cause any significant issues during the lifespan of the case.

Another crack was found on at the inside corner of the primer pocket as shown in figure 10.

Figure 10 – Crack at inside corner of primer pocket in sample A-6-1 (50 times magnification) Cartridge in vertical position

This crack was not noted in the factory stage samples but was noted in most cartridges after this point. The crack could therefore be caused by the primer pocket uniform procedure as described in section 5.1 but could have been missed in the examination of the factory stage samples and thus be a product of the manufacturing process. Like the crack at the inner base of the cartridges no propagation was observed and due to the large wall thickness at this point it is likely that that this crack will have little effect on the operation of the cartridge.

A more worrying crack was observed at the base of the neck of some of the cartridges from sample sets C and DCA. The neck turning process, described in section 5.2, was found to produce a 'step' at the start of the shoulder of some of the cartridges that it was used on. In some of the cartridges a crack was observed to from at the inner corner of this 'step'. Such a crack is shown in figure 11.

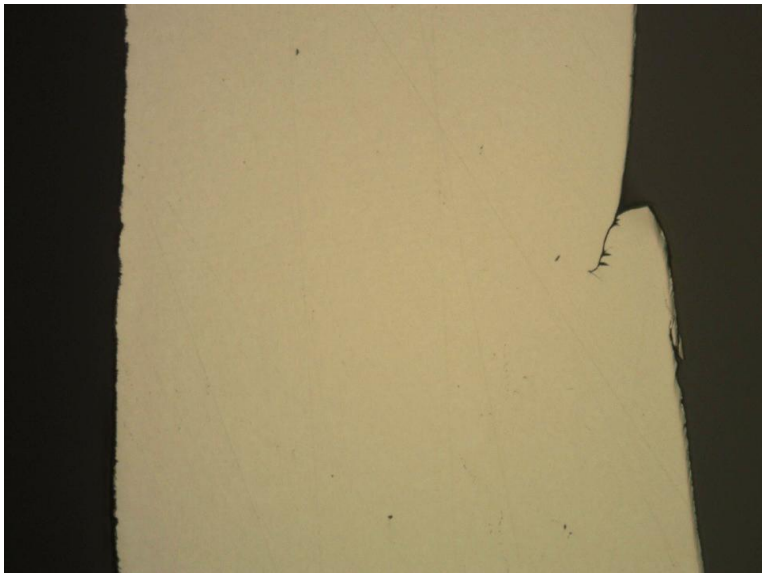

Figure 11 – Crack at base of neck in sample C-9-3
(200 times magnification) Cartridge in vertical position

The crack shown in figure 11 is small in comparison to the wall thickness of the neck of the cartridge. This area of the cartridge is put under large stresses during firing and reloading and it is possible that the crack could be caused to propagate by successive firing-reloading cycles. On some of the neck turned cartridges a burr was observed at this point as shown in figure 12.

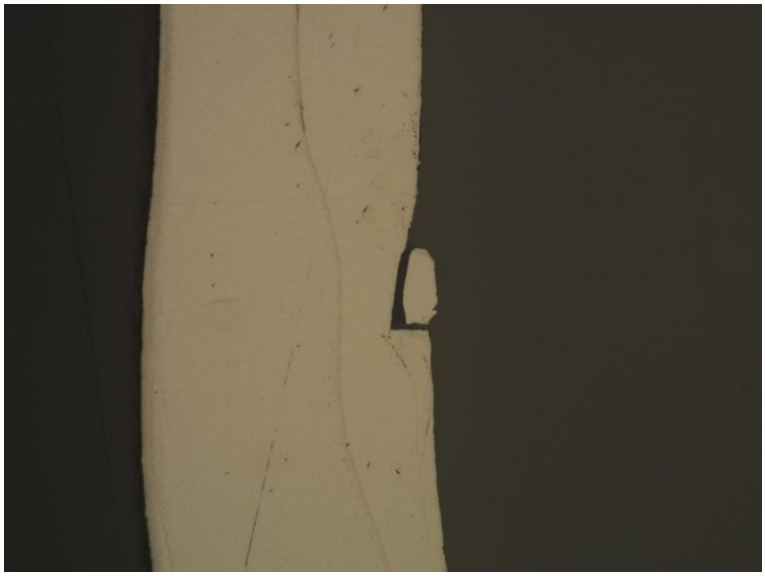

Figure 12 – Burr at base of neck in sample C-11-3
(200 times magnification) Cartridge in vertical position

Figure 12 clearly shows the 'step' and burr that can be formed by neck turning. The ability for a crack to form from this 'step' suggests care should be taken while neck turning. If the neck turning process was not taken so far down the neck of the cartridge it would not cut into the shoulder and thus would not produce a 'step'. This small change to the neck turning process could increase the useful life of the cartridge.

Wall thinning was observed close to the base of the cartridge and is shown in figure 13.

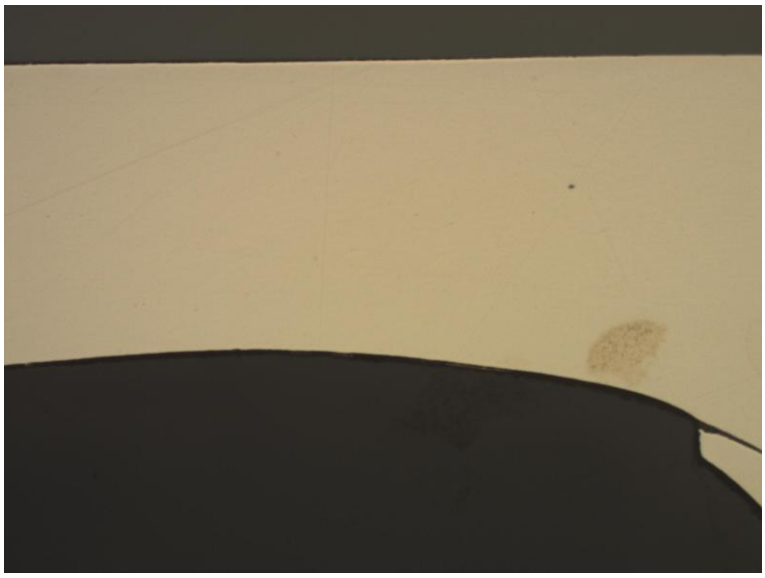

Figure 13 – Wall thinning at base in sample DCA-12-2
(50 times magnification)

This wall thinning seems to be the cause of 'Case-Head Separation' as described by Germán A. Salazar; in his blog 'The Rifleman's Journal'[25]. The thinning is thought to be caused by the successive resizing of the cartridge case. The resizing causes material to flow from the lower areas of the cartridge towards the shoulder and neck thus causing thinning at the base. The failure of cartridge cases due to this phenomenon is well documented[25] and can be avoided by regular inspection and the disposal of affected cases. Many of the cartridges examined during the project exhibited this wall thinning but there were no examples of serious wall thinning that would warrant disposal of the cartridge.

After the cartridge-resin samples were examined under the microscope they were re-polished and etched as described in section 7.

7.0 Microstructure Analysis

The next experimental procedure was undertaken to examine the microstructure of the cartridge samples.

7.1 Experimental Procedure

After the cartridge-resin samples were examined un-etched, as described in section 6.1, they were re-polished using the final polishing disk (abrasive grain size of less than 1µm) and the silica oxide polishing solution.

The samples were then etched using an acidified potassium dichromate solution. Originally alcoholic ferric chloride was tried as an etching solution but this did not satisfactorily reveal the material microstructure. The contents of the acidified potassium dichromate solution were 2g potassium dichromate, 8ml sulphuric acid, 1 drop hydrochloric acid and 100ml of water.

After the samples had been etched they were again examined on the optical microscope.

7.2 Results and discussion

The microscopic examination of the factory stage cartridges showed fine, equiaxed grains at the neck of the cartridge, an elongated grain structure throughout the body of the cartridge and large grains towards the base of the cartridge. This is shown in figures 14, 15 and 16 respectively.

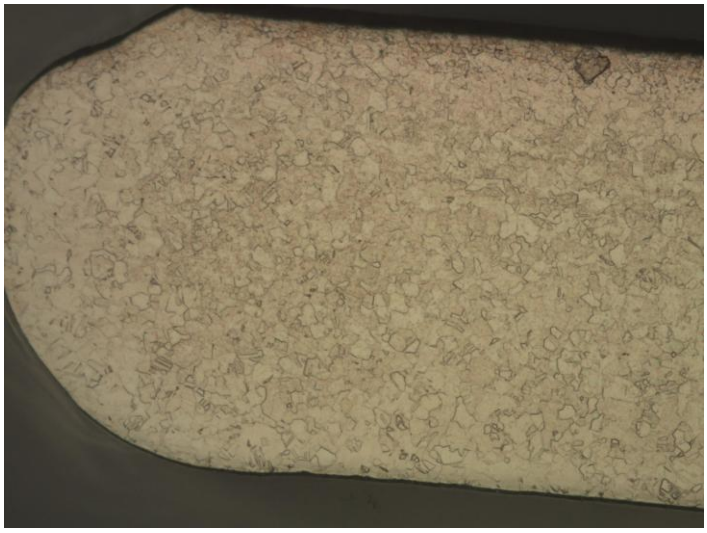

Figure 14 – Microstructure at end of neck; sample 0-1 (200 times magnification)

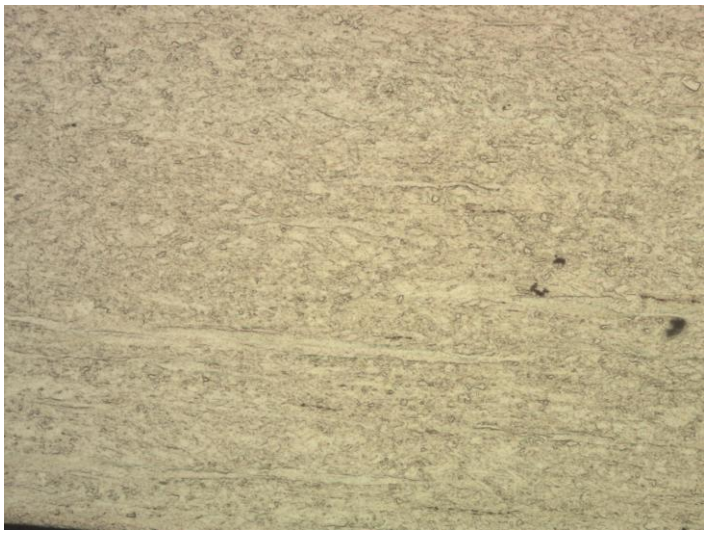

Figure 15 – Microstructure at middle of body; sample 0-1 (200 times magnification)

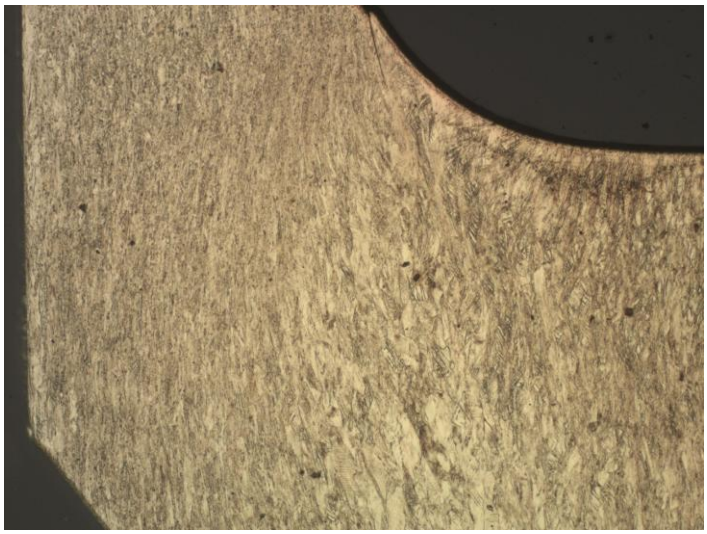

Figure 16 – Microstructure at base; sample 0-1 (200 times magnification)
Cartridge in vertical position

As all of the above figures were taken from a factory stage cartridge the microstructure characteristics can be said to be caused by the cartridge manufacturing process. The fine grain structure at the neck, as shown in figure 14, can be seen to be caused by an annealing stage in the manufacturing process. This is suggested by the small, equiaxed grain structure that shows some evidence of annealing twins. Annealing twins are often present in the microstructure of an annealed material and are thought to be formed by a change in crystalline stacking sequence[17].

Figure 15 shows an elongated grain structure which is most likely caused by the drawing processes used in the manufacture of the cartridges. The transition from this structure to a larger grain structure, at the base, is shown in figure 16. The larger grains which are present at the bottom right hand side of figure 16 are not fully equiaxed but are certainly less elongated than the structure present in figure 15.

Upon examination of sets A and C no major microstructure changes were observed in comparison to the factory stage structure. Figures 17, 18 and 19 show the microstructure at the middle of the neck of samples from the factory stage, set A (stage 11 – prep 6) and set C (stage 11) respectively.

Figure 17 – Neck microstructure; Stage 0 (factory) (200 times magnification)

Figure 18 – Neck microstructure; Stage 11; sample set A (200 times magnification)

Figure 19 – Neck microstructure; Stage 11; sample set C (200 times magnification)

A visual inspection of the above figures shows little change in grain size or microstructure. It is likely that the properties of the brass do change however this cannot be quantified from a purely visual inspection. This suggests that the extreme pressures and temperatures that the cartridges are exposed to during firing are not prolonged enough to severely alter the microstructure of the material.

The microscopy did reveal large variation in the material grain structure of the annealed cartridge samples. This was shown by visible variation in grain size between cartridges that were annealed using the same process (as described in section 5.3). In some cases there was visible variation of grain size between two sides of the same cartridge. This is shown in figures 20 and 21.

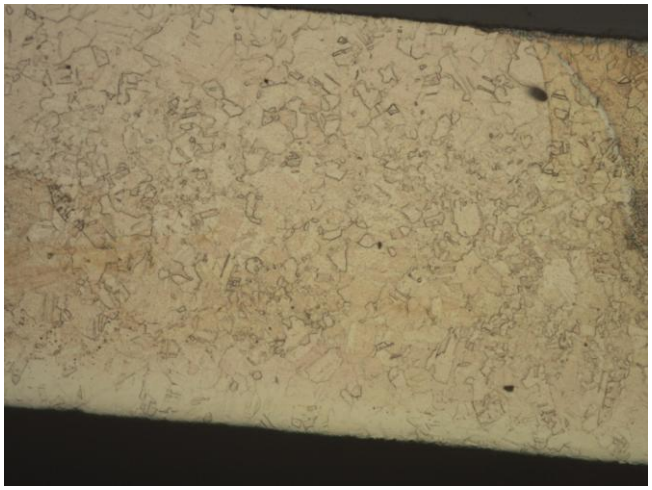

Figure 20 – Neck microstructure; Stage 7; sample set BAA (200 times magnification)
Cartridge BAA-7-1 RHS of neck

Figure 21 – Neck microstructure; Stage 7; sample set BAA (200 times magnification)
Cartridge BAA-7-1 LHS of neck

Figures 20 and 21 show the neck microstructure of both sides of cartridge BAA-7-1. The difference in grain size between the two sides of the cartridge can clearly be seen and highlight the variability of results that are achieved by using the annealing process as described in section 5.3. The examination of the neck annealed cartridges also showed a grain structure transition point roughly positioned at the base of the neck. This is shown in figure 22.

Figure 22 – Transition point; sample C-12-2 (200 times magnification)

The above figure clearly shows a transition between large grains on the LHS and smaller grains on the RHS. All of the grains are equiaxed which suggests that the grains have all achieved recrystallisation during the annealing process but have had differing amounts of grain growth. It is likely that this is due to the fact that the heat is applied to the cartridge neck, causing a heat distribution with the hottest temperature at the neck and progressively cooler temperatures at points further down the cartridge. A cooler temperature would slow the rate of annealing thus resulting in smaller grain sizes at the points of the cartridge where the lower temperatures were able to achieve recrystallisation. The inconsistency of the annealing process is further shown by the fact that the transition point varies in position between the annealed cartridges. This suggests that annealing process is not able to apply consistent amounts of heat to each cartridge that is annealed.

Copper has the ability to dissolve large quantities of zinc in alloy formation [17]. Due to this fact; cartridge brass (30% Zn) is usually well within the face centred cubic α phase of brass[11, 17]. This can be easily seen by referring to the phase diagram as shown in figure 4. Thus the rate of cooling after the annealing process should not greatly affect the microstructure of the material as long as the cooling process can be kept consistent for all of the annealed cartridges. The variability in annealing results is therefore most likely caused by an inability to accurately control the temperature and time of the heat treatment process.

The microstructure variability after annealing will have consequences for shooting accuracy as one round may react differently to another. Large variations in microstructure, with circumferential position, in a single cartridge may affect the way in which a bullet leaves the cartridge during firing and thus further affect shooting accuracy. This raises questions as to whether an improved cartridge annealing process could be used or whether cartridge lifespan should be sacrificed to maintain shooting accuracy by not including cartridge annealing in a reloading process.

After the microstructures of the samples were examined by optical microscope; the samples were hardness tested using a Vickers micro hardness tester.

8.0 Vickers micro hardness

Hardness testing was carried out to quantify the change in material properties of the cartridges caused by successive firing-reloading procedures and the annealing process as described in section 5.3.

8.1 Experimental Procedure

After the microscopy was completed the bases of the resin samples were ground to ensure the samples were level. This allowed the samples to be hardness tested using a Vickers micro hardness tester with an applied load of 200g for 15s. Initially the Vickers hardness was measured at 10 points on the cartridge as shown in figure 23.

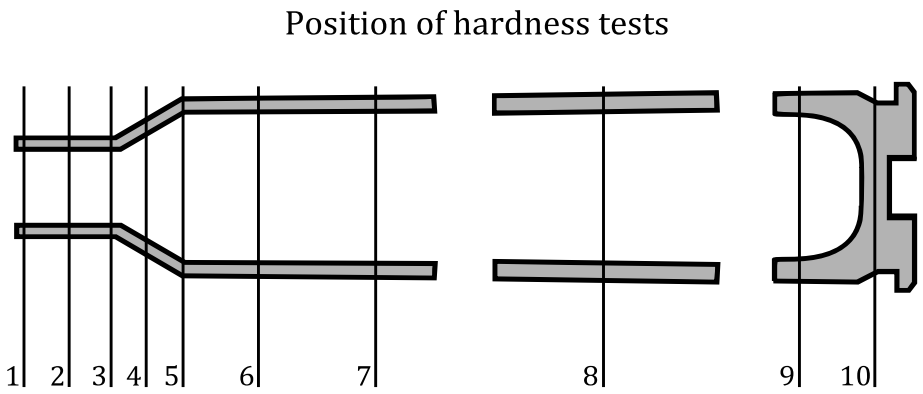

Figure 23 – Vickers hardness measurement positions

These measurement points were made as close to the middle of the cartridge wall as possible and were defined as a length from the neck or base of the cartridge as detailed in table 6.

Measurement number (as on figure 23)	Position from cartridge neck (mm)	Position from cartridge base (mm)
1	0.1	
2	3.0	
3	6.0	
4	9.0	
5	14.0	
6	17.0	
7	22.0	
8	Rough middle point	
9		7.0
10		2.0

Table 6 – Position of Vickers hardness measurements

Ten measurements were taken on all cartridge-resin samples up to stage 5 (prep 3). Towards the end of the project and due to time constraints the hardness tests were reduced to one measurement per sample. This measurement was taken at the middle of the cartridge neck (position 2 as on figure 23). This reduction in measurements was made to allow the project to be completed to the deadline.

8.2 Results and discussion

As described in section 8.1 the initial Vickers hardness measurements were taken at ten positions on each cartridge-resin sample. Figures 24, 25 and 26 show plots of these readings for cartridge stage 0 (factory), A-5 (set A, prep 3) and C-5 (set C, prep 3) respectively.

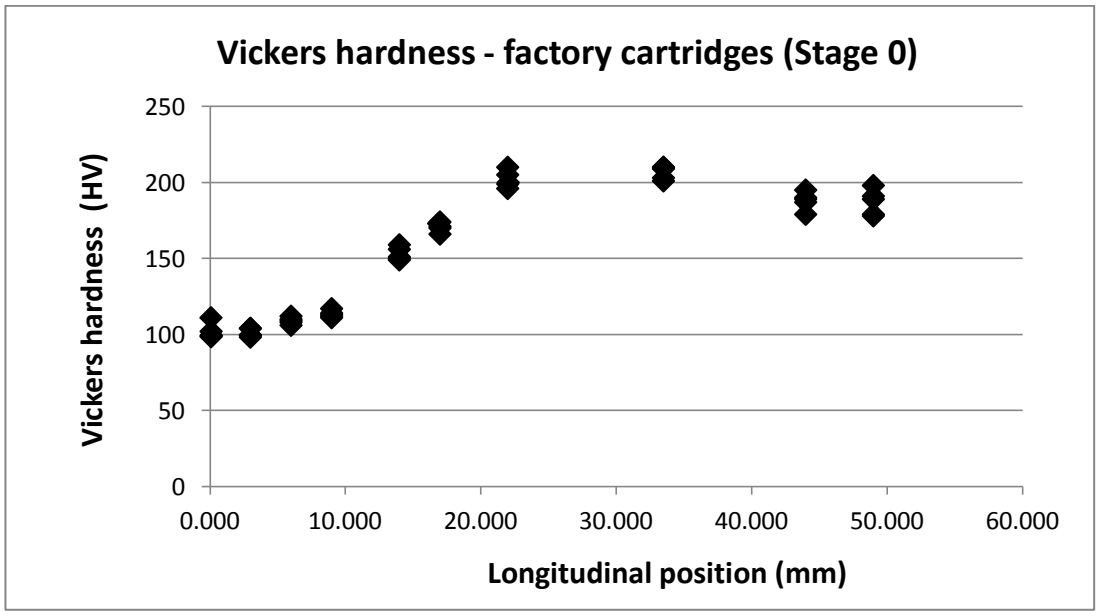

Figure 24 – Vickers hardness measurements on stage 0 cartridges

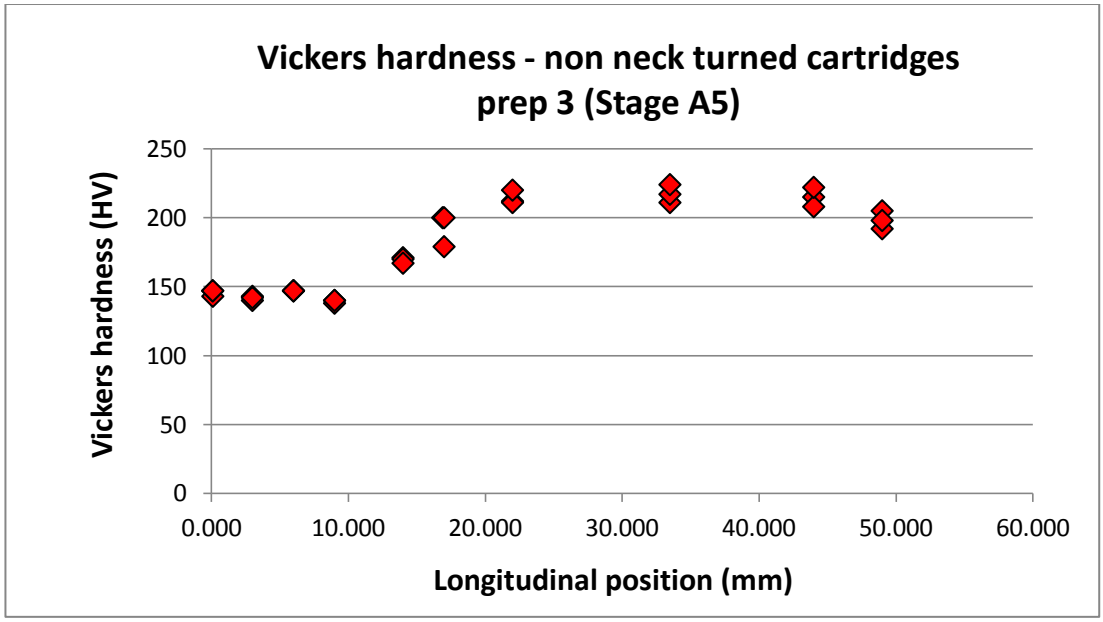

Figure 25 – Vickers hardness measurements on stage 5 cartridges; sample set A

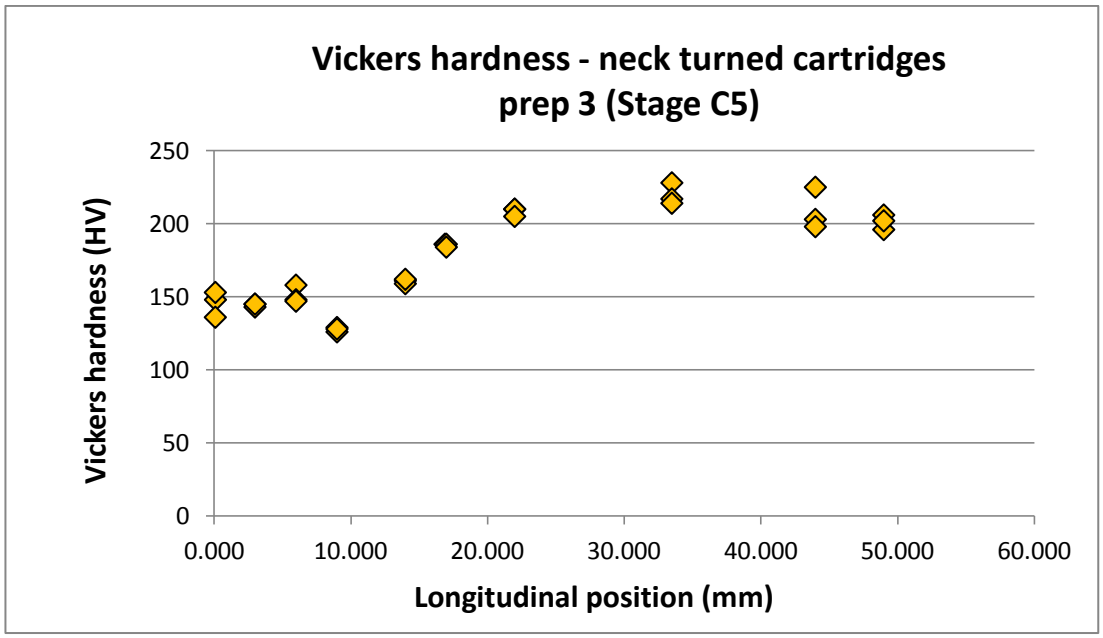

Figure 26 – Vickers hardness measurements on stage 5 cartridges; sample set C

From figure 24 it can be seen that when exported from the factory the cartridges have a hardness of roughly 100HV at the neck which increases to roughly 200HV towards the base of the cartridge. Figures 25 and 26 show that after two firings and three prep stages; the cartridges exhibit a neck hardness of around 150HV while the lower part of the body of the cartridges is around 220HV. From these results it can

be seen that the work hardening during the use of the cartridges is concentrated at the neck area. This suggests that it was sensible to focus on the neck area when a reduction in measurement numbers had to be made. The average hardness measurements of all the sample sets are plotted on the graph shown in figure 27.

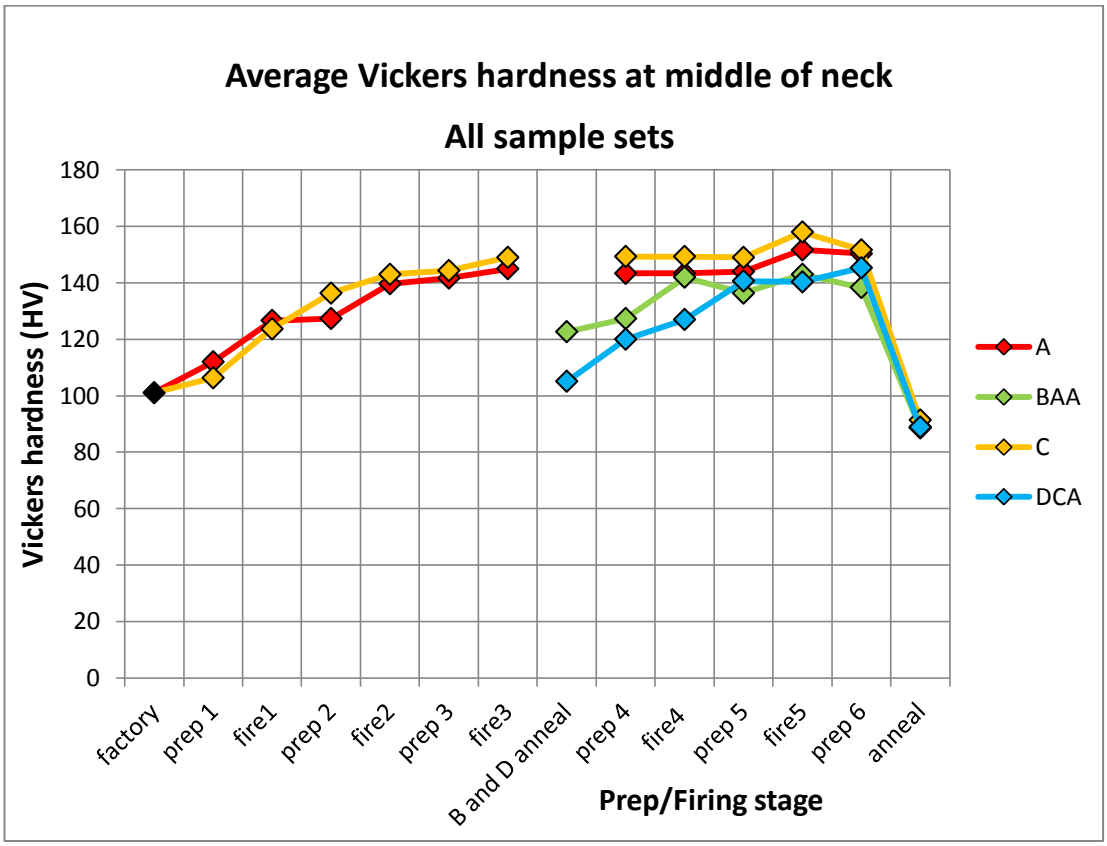

Figure 27 – Average Vickers hardness; all sample sets

The above figure shows the increase in hardness of the brass at the cartridge neck through use. It is interesting to note that the largest increases in hardness are caused by the firing stages of the process. This suggests that the working of the cartridge to prepare it for firing has little impact in comparison to the work hardening produced by the pressure exerted on the cartridge during firing.

The figure also shows that the material hardness at the neck is very similar for sample sets A and C. This suggests that the neck turning process, included in the preparation procedure of sample set C (and DCA) does not significantly affect the hardening of the cartridges throughout their lifespan.

The graph also shows that the annealing of sample sets BAA and DCA after the third firing have differing results. Despite this the annealing process, as described in section 5.3, does significantly reduce the hardness of the brass at the cartridge neck. It can be seen that after the first annealing process the hardness of the annealed samples quickly increase; nearly equalling the hardness of their parent sets (A and C) by prep stage 6. This suggests that if annealing is to be carried out it should be done on a regular basis.

The final annealing procedure, on all sample sets (stage 12), seemed to achieve relatively consistent results. The final hardness measurements recorded all being around 90HV. It is interesting to note that the hardness achieved was below that of the neck hardness of the factory stage for which an average hardness of 101HV was recorded.

The inconsistencies in the results achieved from the annealing procedure, as seen in the examination of material microstructure (section 7.2) were further illustrated by including the standard deviation of the measurements in the hardness plot. Figures 28 and 29 show the average Vickers hardness measurements and standard deviation of sample sets (A and BAA) and (C and DCA) respectively.

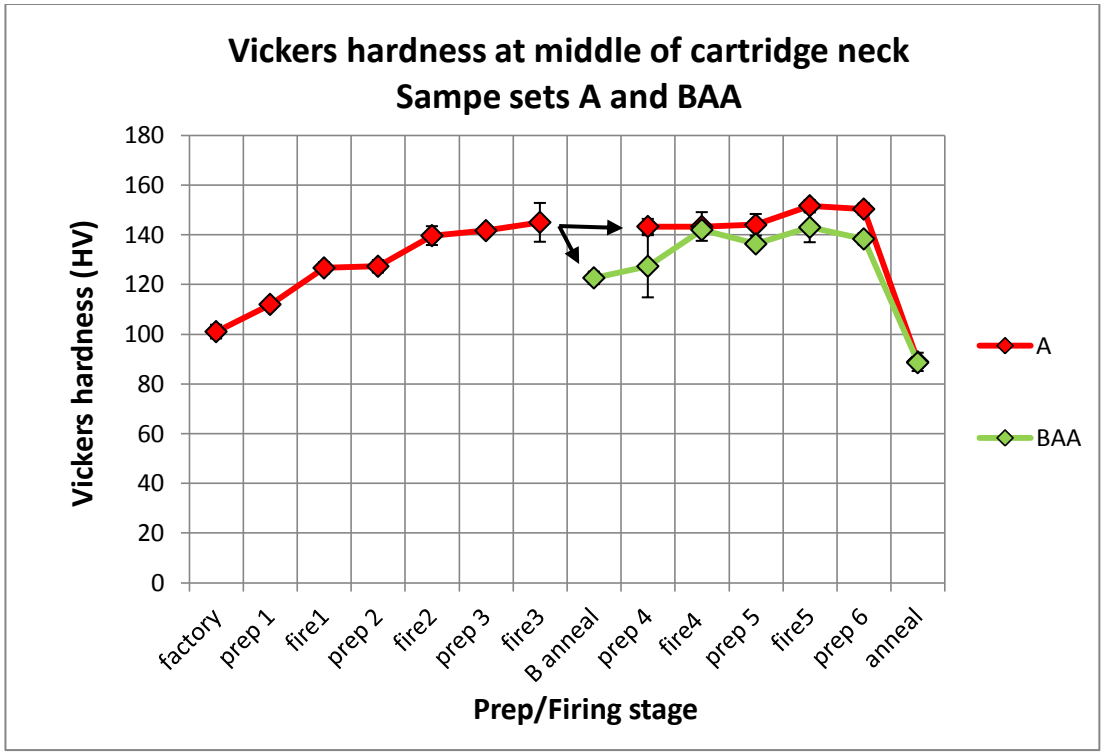

Figure 28 – Average Vickers hardness of sample sets A and BAA with error bars representing standard deviation

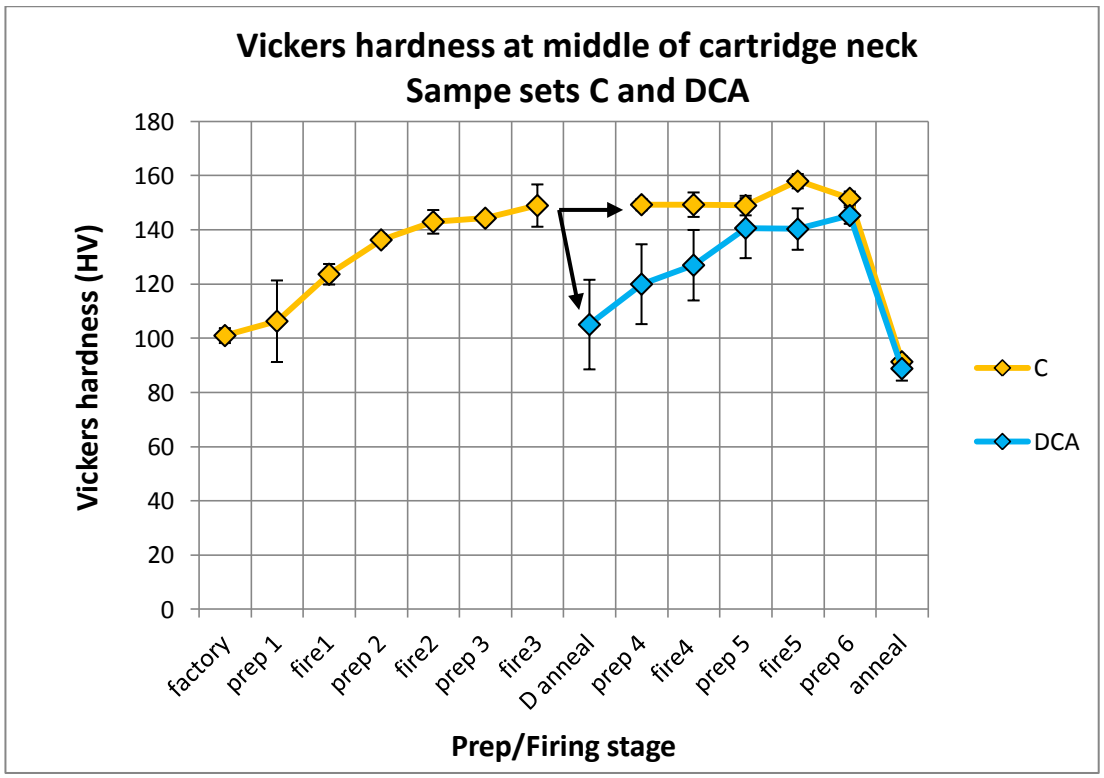

Figure 29 – Average Vickers hardness of sample sets C and DCA with error bars representing standard deviation

Arrows have been superimposed onto the figures to show the relationship between the parent sample sets (A and C) and the sample subsets (BAA and DCA).

The variability of the annealing process is shown by the large error bars in figures 28 and 29 representing standard deviation of the hardness measurements. The variability is highlighted by the fact that the error bars on the annealed subsets (BAA and DCA) are much greater than that of the parent sets (A and C). This is especially apparent in figure 29.

The results quantify the work hardening of the cartridges throughout their lifespan and show that the cartridge neck annealing process can significantly reduce the hardness and therefore increase ductility of the material. Like in section 7.2; the results suggest that an improvement in the neck annealing process could greatly increase the ability to control the material properties of the cartridge cases. A more controllable annealing process would decrease the variability of the annealing results achieved and could help to maintain accuracy when shooting.

9.0 SEM

A Scanning Electron Microscope (SEM) was used to perform a chemical analysis by Energy Dispersive X-ray Spectrometry (EDS) on selected cartridge-resin samples.

9.1 Experimental Procedure

After the hardness testing was completed selected cartridge-resin samples were coated in a film of gold. This was done to help dissipate the charge when examining the samples using the SEM. Using the SEM, Energy Dispersive X-ray Spectrometry (EDS) was used to perform a chemical analysis of the samples.

Due to time constraints, chemical analyses were only performed on two cartridge-resin samples. These were a stage 0 (factory) sample and sample from set A, stage 4 (prep 2). The chemical analyses were carried out at five points along the length of the cartridge.

9.2 Results and discussion

The results of the EDS chemical analyses showed a variation of copper content of between 67.46% and 75.02% (by weight). The results were plotted on a graph as shown in figure 30.

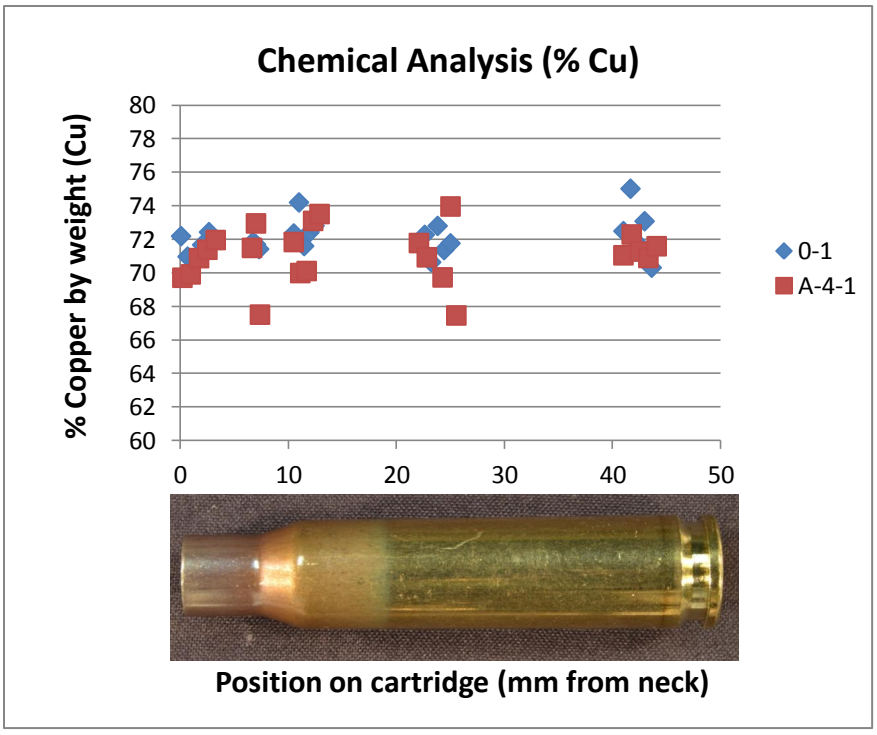

Figure 30 – Copper content of cartridges

The results show a large variation in copper content which is outside the range of 68.5-71.5% as specified by the ASTM International Standard Specification for Cartridge Brass cartridge Case Cups[3]. From figure 30 it can be seen that the measured copper content is just as variable for both samples tested. This suggests that there may be errors contained within the results.

The cartridge-resin samples were not ideal for chemical analysis due to the fact that the resin did not dissipate the charge of the electron beam. The gold coating, described above, was applied in an effort to combat this but probably did not produce the ideal conditions for assessing the chemical content of the brass. Further errors could have been introduced by oxidation on the surface of the samples. It is thought that a more successful analysis could be performed by lightly grinding a whole cartridge sample to remove any oxidation on the surface of the cartridge. As this sample would not include any resin; the charge of the electron beam should be easier to dissipate. Unfortunately there was not sufficient time to try this experimental procedure.

Despite the large variation in chemical results; the majority of the results are around a copper content of 70%. This suggests that the cartridges are produced from a 70/30 cartridge brass.

10.0 XRD

An X-Ray Diffraction machine was used to perform a residual stress analysis on selected cartridge samples. The samples that were examined using the XRD machine are detailed in table 7.

Stage	Stage No.	Sample Set A	Sample Set BAA	Sample Set C	Sample Set DCA
Factory	0	1			
Prep 1	1				
Fire 1	2				
Prep 2	3				
Fire 2	4				
Prep 3	5				
Fire 3	6	1		1	
B and D Anneal	A1				
Prep 4	7				
Fire 4	8				
Prep 5	9				
Fire 5	10	1	1	1	1
Prep 6	11				
Anneal	12				
TOTAL CARTRIDGES		**7**			

Table 7 – Cartridges examined using XRD

These samples were chosen for the residual stress analysis to try to achieve an overview of residual stresses throughout the lifespan of the cartridges.

10.1 Experimental Procedure

An X-Ray Diffraction (XRD) machine was used to perform residual stress analyses on selected cartridge samples as defined in table 7. The cartridges were examined whole to avoid releasing any stresses contained within the cartridge structure. Due to the nature of the XRD technique the measured residual stresses are those present in a very thin layer of material below the surface of the cartridge and can be regarded as residual stresses at the outer surface [23].

Residual stress analyses were performed at five points along the length of the stage 0 (factory) cartridge. This was done in an attempt to define the residual stresses in a cartridge just after manufacture.

Residual stress analyses were carried out at three points along the A-6 (fire 3) and A-10 (fire 5) cartridge samples to try to classify how successive firing-reloading procedures affect the residual stress contained within the cartridges.

Due to time constraints only one residual stress measurement was performed on the other cartridge samples. This was performed at the middle of the cartridge neck as this was seen to be the position on the cartridge where stresses would have the most influence on a bullet and therefore shooting accuracy.

10.2 Results and discussion

Figures 31 and 32 depict the circumferential and longitudinal residual stress results as measured using XRD in the stage 0 (factory cartridge). From the results it can be seen that the magnitude of residual stress is low at the neck of the cartridge and increases along the length of the cartridge. A photograph of a cartridge has been included in the figures to help to show the position of the residual stresses on the cartridges.

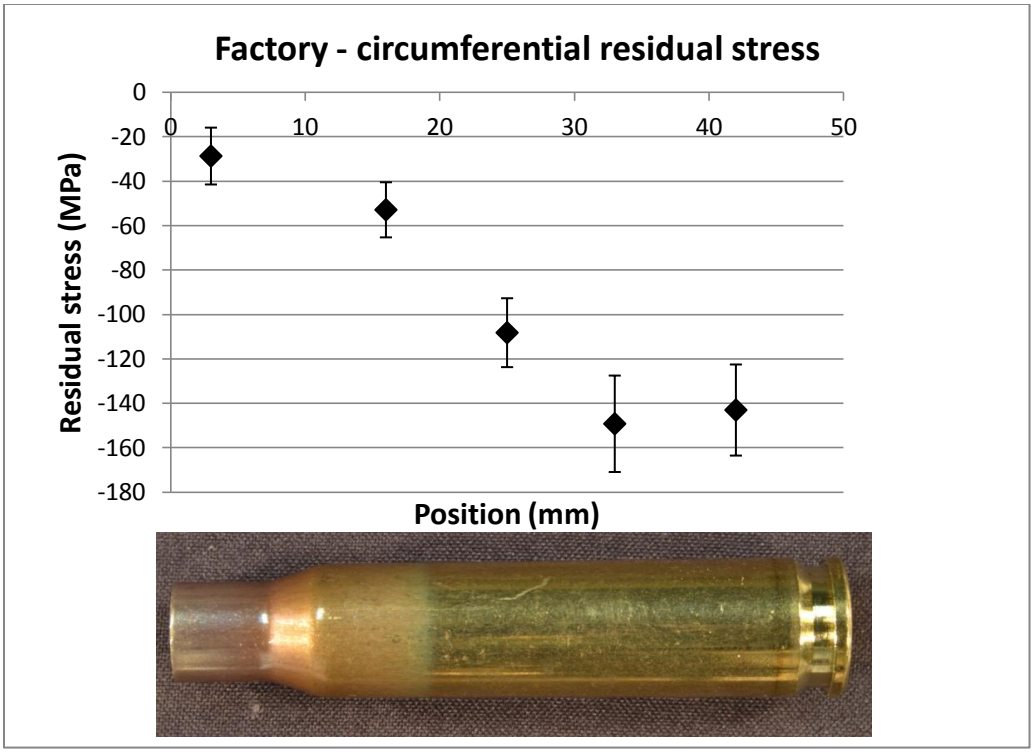

Figure 31 – XRD residual stress measurements; stage 0 cartridge
Circumferential direction

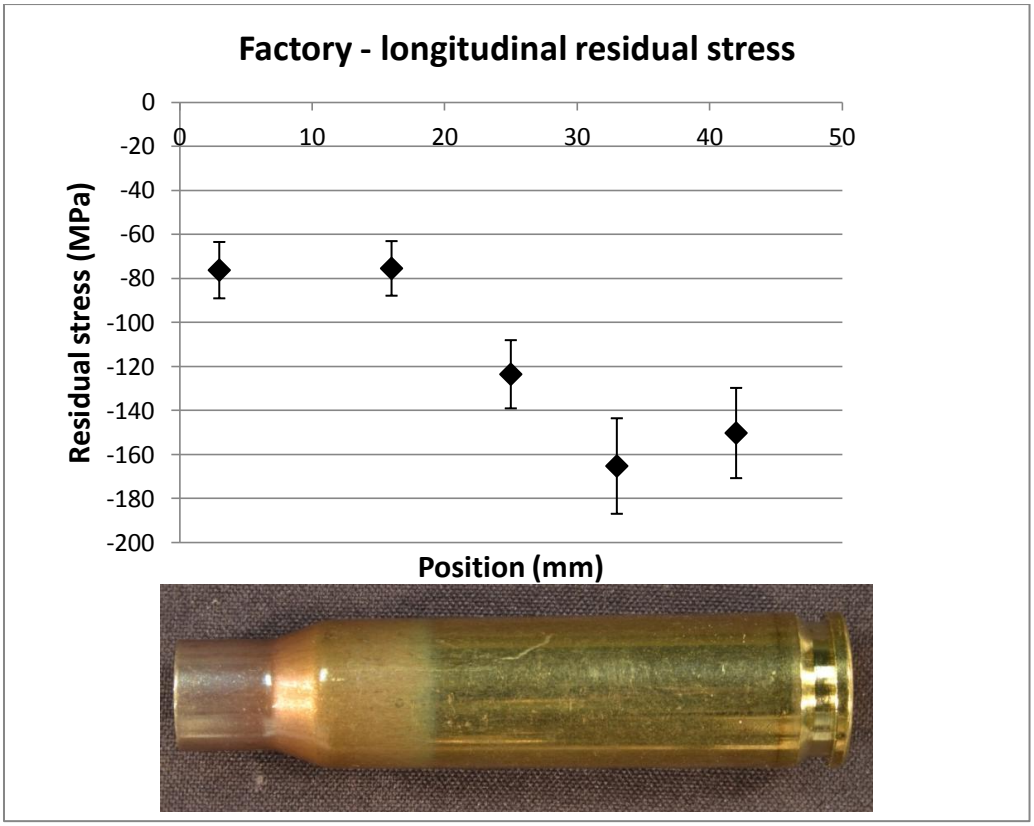

Figure 32 – XRD residual stress measurements; stage 0 cartridge
Longitudinal direction

From the above figures it can be seen that all of the residual stresses are negative; showing that the stresses are all compressive. This suggests that the later processes in the manufacture of the cartridges, such as the necking procedure used to produce the neck of the cartridge, cause the cartridge to exhibit compressive residual stresses. The fact that the results indicate compressive stresses is in contradiction to the results achieved by Rosenthal and Mazia[19] in which the stresses were invariably in tension. Rosenthal and Mazia also found that although the longitudinal stresses at the neck of the cartridges were large, the longitudinal stresses at other points in the cartridges were negligible[19]. This again contradicts the residual stress results achieved by XRD and suggests that there may be errors contained within the results.

Figures 33 and 34 show the circumferential and longitudinal residual stresses as measured in the A6 cartridge (sample set A, fire 3) respectively.

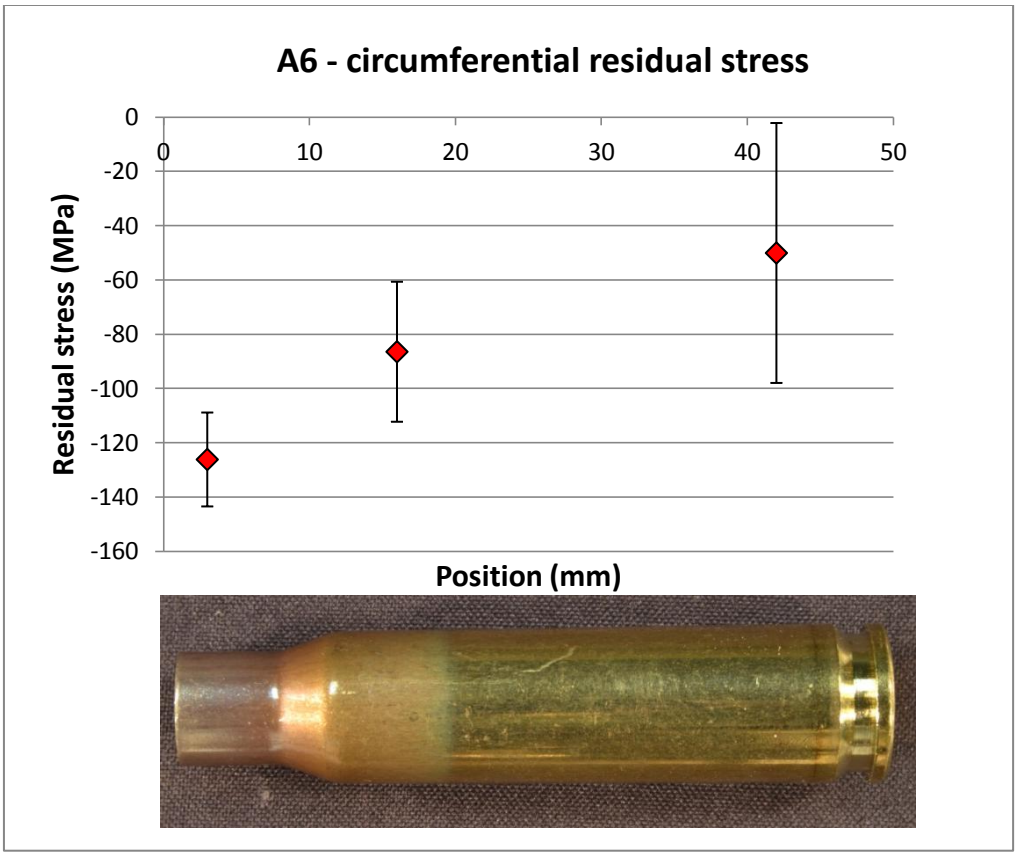

Figure 33 – XRD residual stress measurements; A-6 Cartridge Circumferential direction

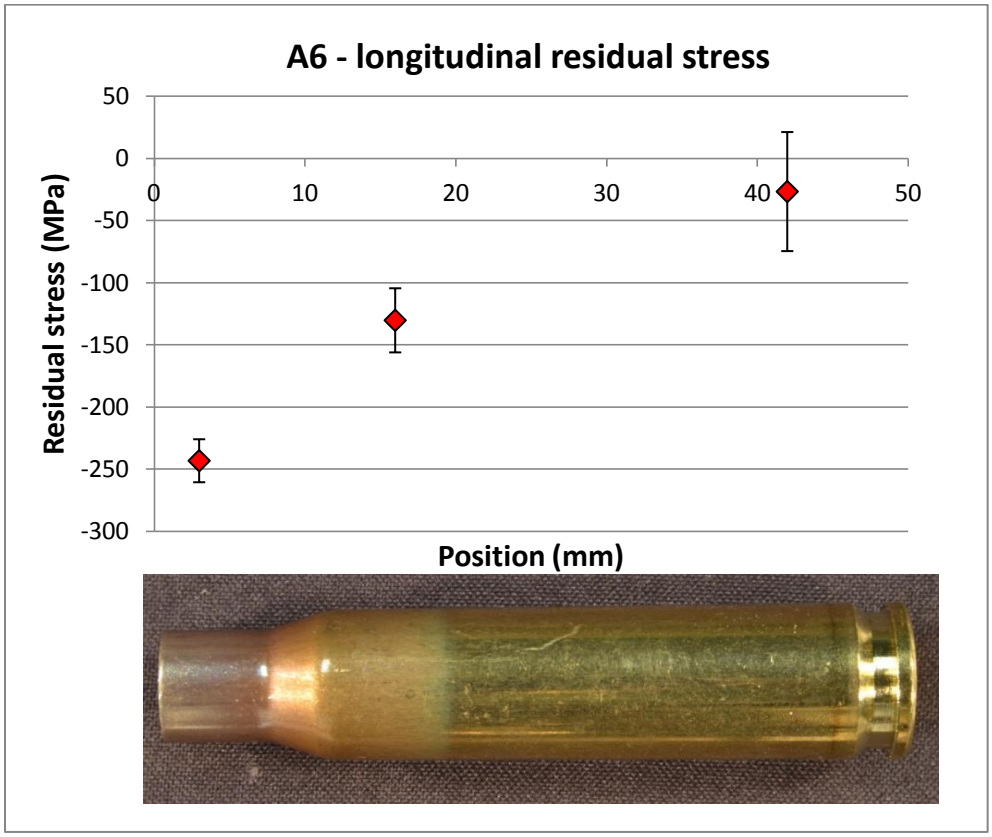

Figure 34 – XRD residual stress measurements; A-6 Cartridge Longitudinal direction

The figures show that after three firings the magnitude of the residual stresses at the cartridge neck are greater than that of the stresses throughout the body of the cartridge. Despite this, the results still show compressive stresses and the longitudinal stresses are still larger in magnitude than that of the corresponding circumferential stresses.

Figures 35 and 36 show the circumferential and longitudinal residual stresses as measured in the A10 cartridge (sample set A, fire 5) respectively.

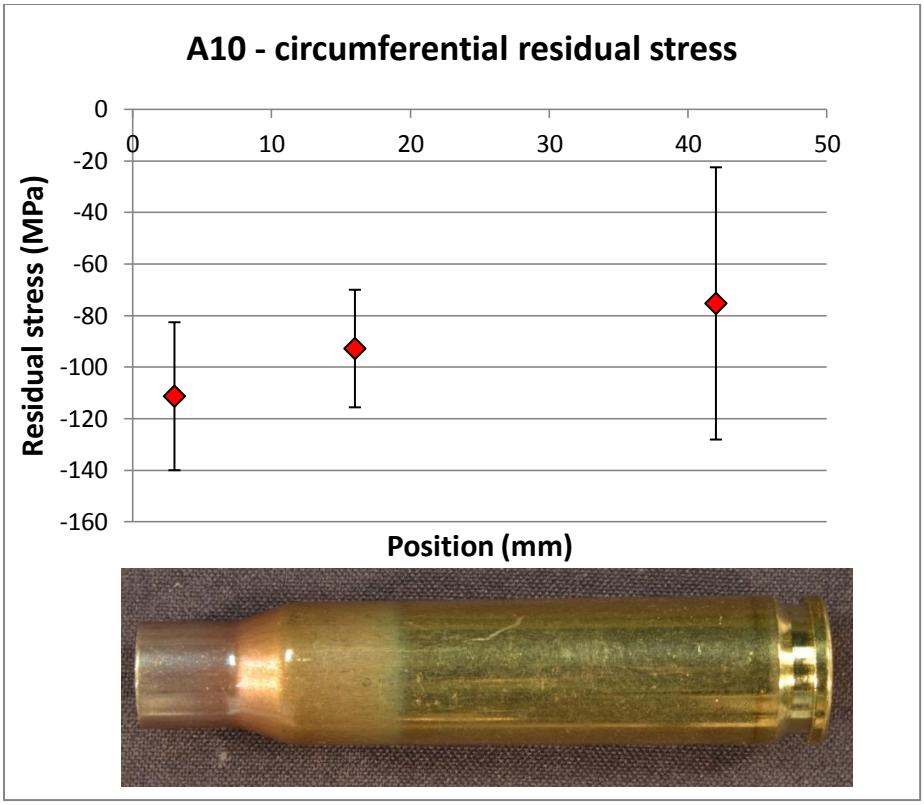

Figure 35 – XRD residual stress measurements; A-10 Cartridge Circumferential direction

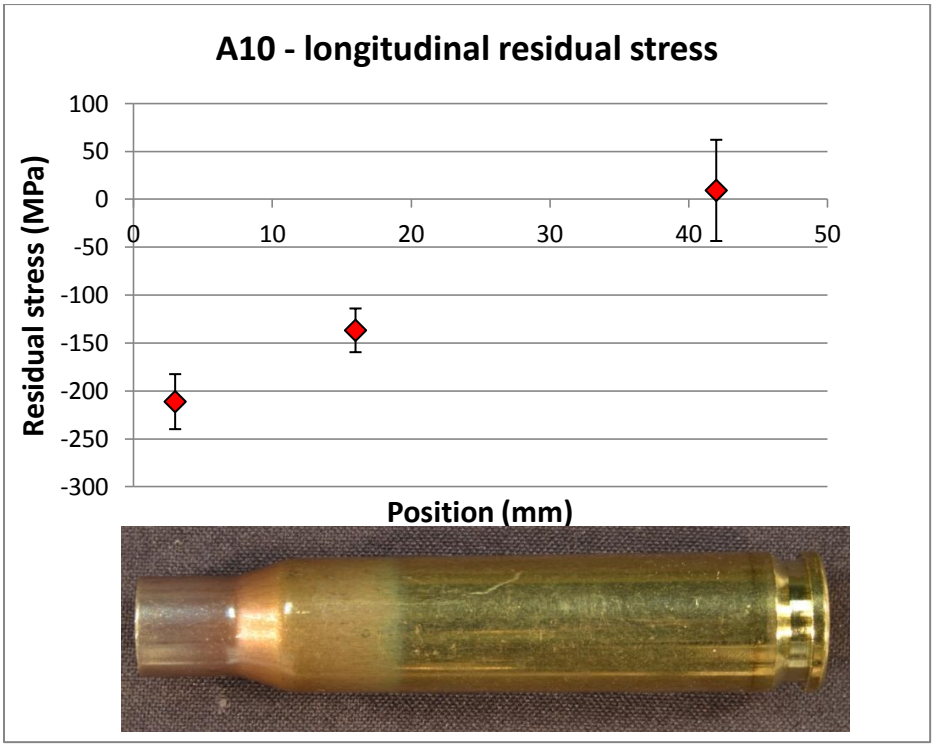

Figure 36 – XRD residual stress measurements; A-10 Cartridge Longitudinal direction

Interestingly the residual stress measurements from the A10 cartridge (fire 5), as shown in figures 35 and 36 are smaller in magnitude that that of the measurements from the A6 cartridge (fire 6). This result was unexpected as the A10 cartridge had undergone more firing-reloading cycles than the A6 cartridge and suggests that the residual stress measurements may contain some errors.

Figure 37 shows the circumferential residual stresses at the cartridge neck of all of the samples examined using XRD.

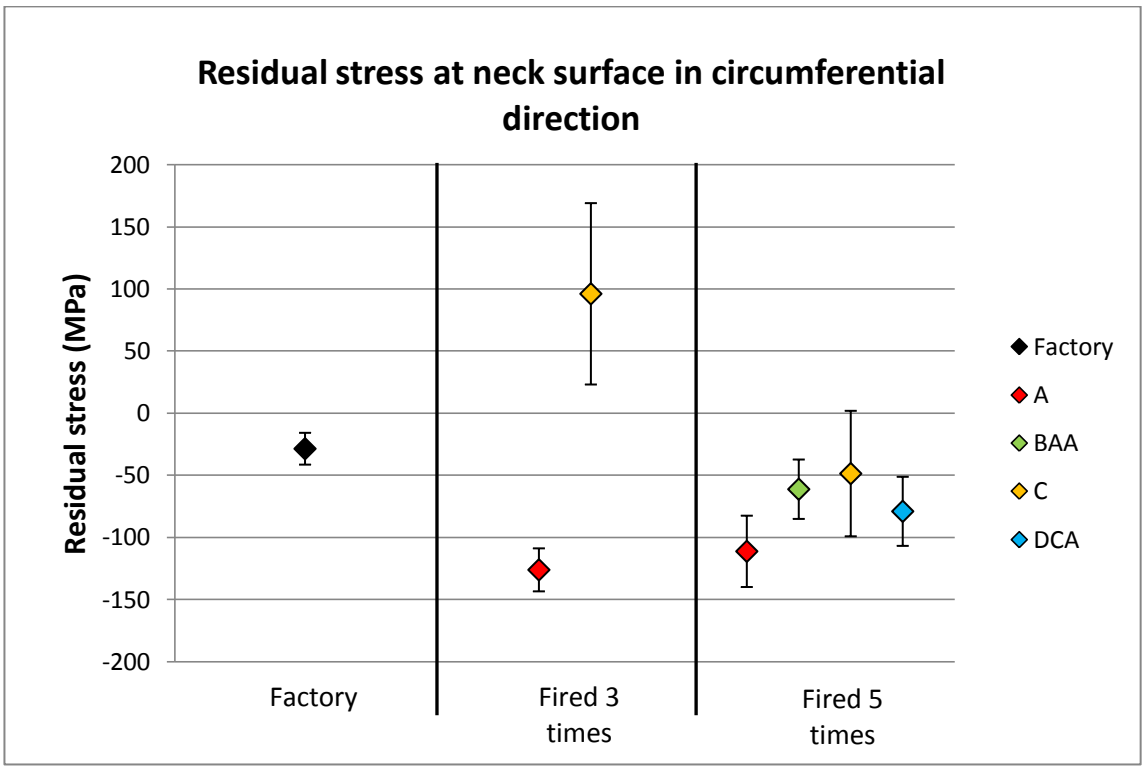

Figure 37 – XRD residual stress measurements at cartridge neck
Circumferential direction

From the graph it can be seen that the resulting stresses are quite variable. Although the magnitude of the stresses of the cartridges fired 3 and 5 times can be seen to be larger than that of the unfired factory case; the magnitude of the stress in the 3 times fired cartridges seem to be larger than that of the 5 times fired cartridges. This again suggests erroneous results.

Figure 38 shows the residual stress measurements in the longitudinal direction of the cartridges.

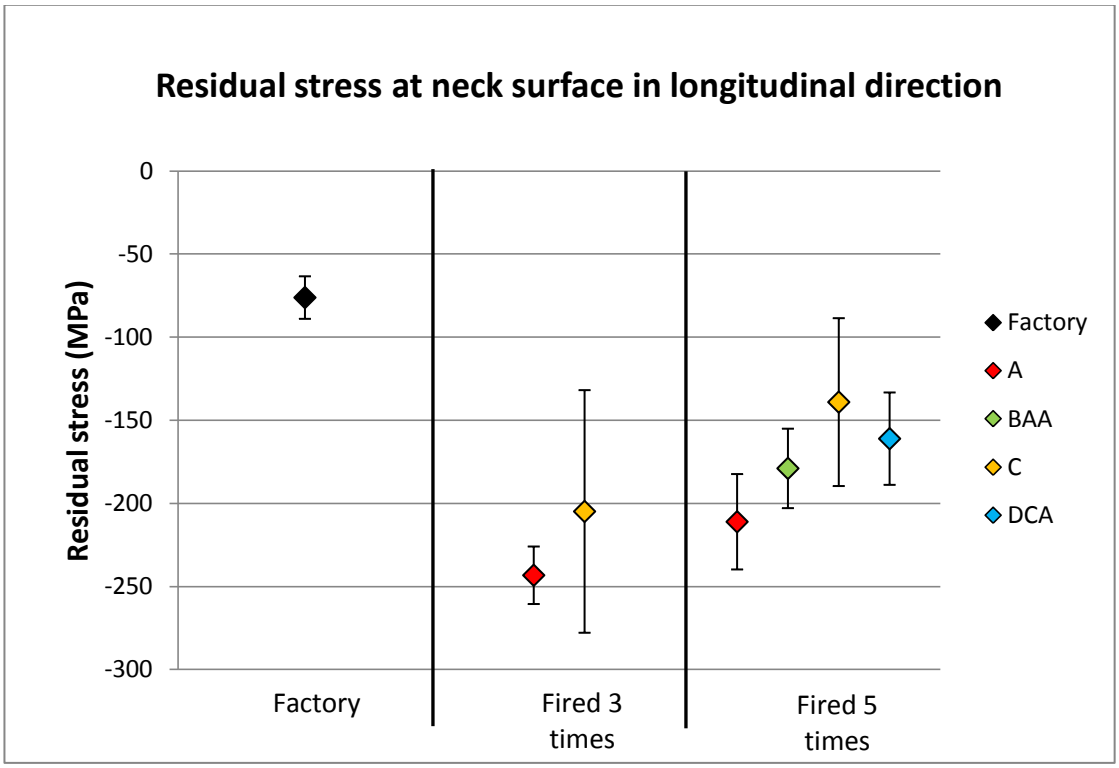

Figure 38 – XRD residual stress measurements at cartridge neck Longitudinal direction

From figure 38 it can be seen that the results are again quite variable and that the magnitude of the residual stresses in the fired cartridges are all larger than that of the unfired factory case. The magnitude of the longitudinal residual stresses are larger than that of the corresponding circumferential residual stresses.

The large errors in all of the residual stress measurements (represented by the error bars) were recorded by the XRD machine as inaccuracies in the calculated residual stresses. The use of a collimator to focus the X-ray beam on the neck of the cartridge samples probably contributed to the error in the readings. The collimator reduced the count rate achieved during the XRD analysis, thus reducing the peak intensity of the X-ray spectra and increasing the error in each reading. It was necessary to use a collimator due to the complex geometry of the cartridges yet accurate positioning of the cartridges under the X-ray beam remained extremely

difficult. This positioning difficulty makes it likely that there are further inaccuracies in the recorded residual stress measurements.

It is interesting that in his paper for the Australian Department of Defence, David Saunders was not able to achieve cartridge residual stress measurements by X-ray techniques[20]. In the paper it is suggested that the reason for this may be that the elongated grain structure of the cartridge, formed during manufacture, may modulate the X-ray data[20]. This effect may provide some explanation of the unexpected results as described above.

Despite the large potential for error it is believed that if XRD residual stress readings were taken on a number of cartridges from the same sample set and stage; the variability of the results could be greatly reduced. This would also help to show whether consistent residual stress measurements could be achieved on cartridge cases. It would also be beneficial to compare the XRD results to another means of measuring residual stress such as the method described by Rosenthal and Mazia in their paper[19]. Unfortunately the timescale of the project did not allow these further experiments to be undertaken.

11.0 Seating/Unseating tests

To measure the force of seating and removing a bullet from a cartridge an experiment was designed. The cartridge samples that were examined during this experiment are detailed in table 8.

Stage	Stage No.	Sample Set A	Sample Set BAA	Sample Set C	Sample Set DCA
Factory	0				
Prep 1	1	3		3	
Fire 1	2				
Prep 2	3	3		3	
Fire 2	4				
Prep 3	5	3		3	
Fire 3	6				
B and D Anneal	A1				
Prep 4	7	3	3	3	3
Fire 4	8				
Prep 5	9	3	3	3	3
Fire 5	10				
Prep 6	11	3	3	3	*
Anneal	12	3	3	3	3
TOTAL CARTRIDGES		**63**			

Table 8 – Cartridge samples examined in seating/unseating experiment

*No cartridges from this stage were examined in the experiment as they had not been prepped and were thus equivalent to stage 10 samples.

11.1 Experimental Procedure

To measure the force of seating and removing a bullet from a cartridge an experiment was designed. A stainless steel 'pull out pin' was produced to approximate a bullet. This pin was a cylinder of diameter 7.849(+0.0 -0.076)mm; equal to the maximum diameter of a 0.308 bullet as defined by SAAMI specifications[12]. A tensile testing machine was used to measure the maximum force of seating the bullet approximation in a cartridge case and then to measure the maximum removal force. Three cartridges from each preparation stage were examined in this way (see table 8).

The experiment was not designed to produce a true representation of the forces applied in a real bullet seating/unseating; but was designed to provide a relative measure that could be used to compare the samples under examination.

11.2 Results and discussion

Before this experiment was undertaken it was hypothesized that changes in the internal neck diameter may have a larger effect on the results than the material properties of the cartridges. To investigate this; the internal neck diameter of each cartridge was measured using a digital Vernier calliper. These measurements are shown in figure 39.

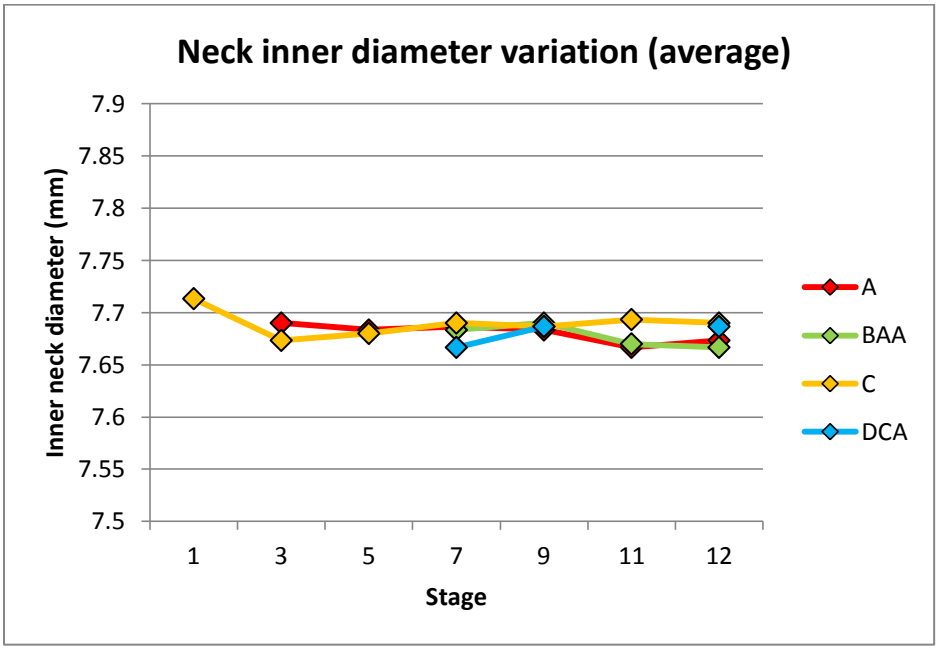

Figure 39 – Variation of internal neck diameter of cartridges

From figure 39 it can be seen that there is little variation in the internal neck diameter of the cartridges and also that the majority of the internal neck diameter measurements are between 7.65mm and 7.70mm.

Figures 40 and 41 show the average seating and unseating force measurements recorded during the experimentation.

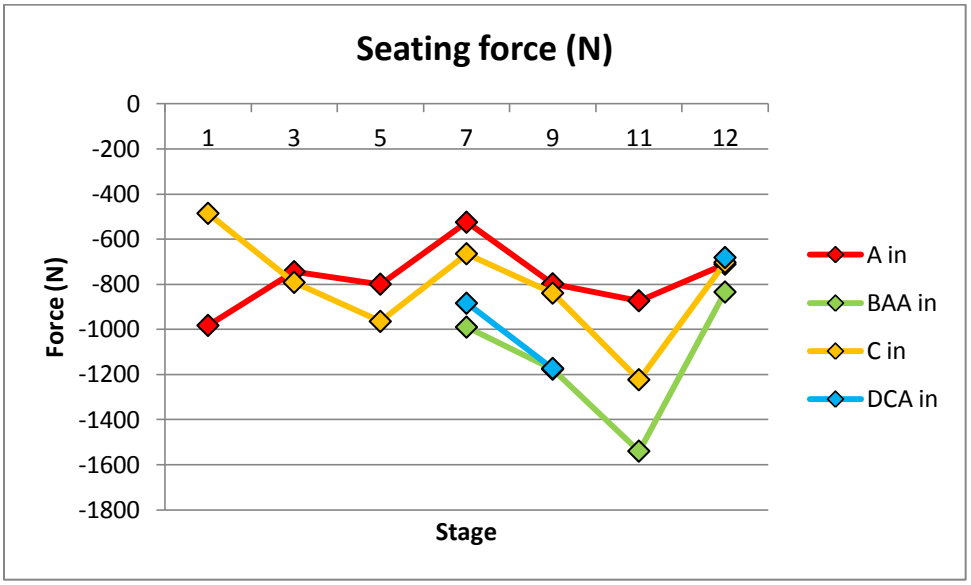

Figure 40 – Average seating force

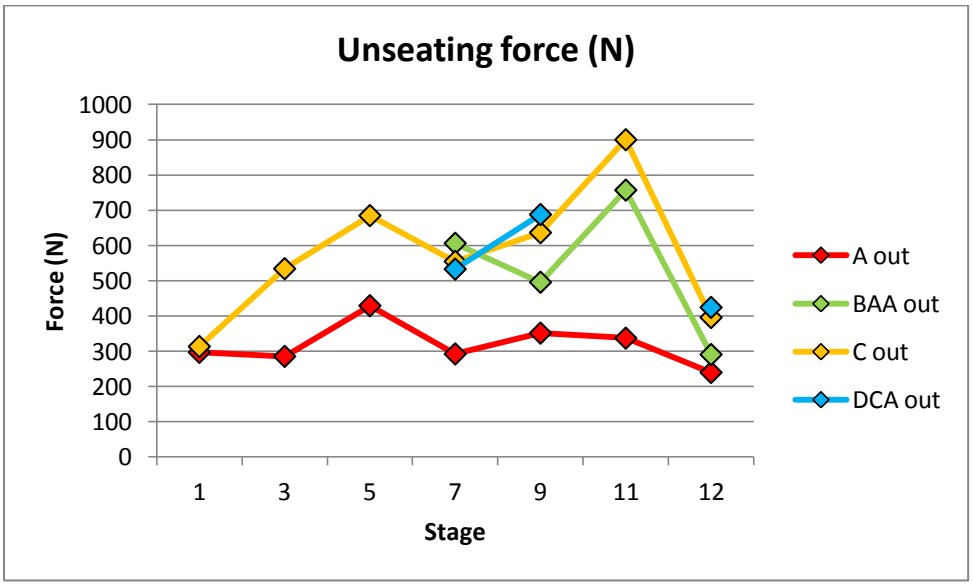

Figure 41 – Average unseating force

From the above figures it can be seen that the results of the experiment are quite variable. Each sample set also showed a large standard deviation when the average seating or unseating force was calculated. The results show limited overall trends and consequently it is difficult to draw any real conclusions from the experiment.

It is believed the experiment could have been improved if real bullets had been used as opposed to the stainless steel bullet approximation (described in section 11.1). This improvement to the experiment would have required a new bullet to be used for each seating and unseating test and thus variation in the bullet sizes could have introduced error. In addition the cost and time implications meant it was not undertaken during the work.

12.0 General Discussion

12.1 Project scope and timescale

The project plan detailed an ambitious investigation into the use of 0.308 brass cartridge cases in successive firing-reloading cycles. As previously mentioned the project required 396 cartridges and 1260 rounds to be fired. This also required Tim Stewart to make numerous trips to the firing range.

The high levels of activity needed to produce the cartridge samples inevitably caused delays in the delivery of said samples. Shooting delays were caused by adverse weather conditions and cartridges were regularly held up in the post due to their 'suspicious appearance'.

The samples also required high levels of preparation to undertake the experimental procedures. The timescale of the project resulted in reduction of some of the planned experimentation. Despite this, a large amount of experimental data was gathered during the investigation.

12.2 Results

From the results achieved, the hardening of the cartridges during use was quantified. Microscopic analysis revealed a number of cracks present in the structure of the cartridges and showed that the microstructure of the cartridges changed very little during use.

It was shown that the annealing process, used by Tim Stewart, produced very variable results. The annealing process was found to significantly reduce the hardness of the material at the neck of the cartridges but produced inconsistent end results.

The chemical analysis (section 9) produced variable results but did suggest that the material used in the production of the cartridges was likely to be a 70/30 brass.

Limited conclusions were able to be drawn from the XRD residual stress analysis and the seating/unseating tests but methods of improving the results were suggested.

The work undertaken could not hope to investigate all aspects affecting accuracy in high end target shooting but the results achieved provided some interesting information regarding the reaction of 0.308 Lapua cartridge cases to successive firing and reloading.

12.3 Further research

There are a number of aspects involved in shooting that could warrant further research. A few of these are:

- How the geometry of the cartridge changes during use (to investigate the flow of the brass).
- How the soot left inside a cartridge after firing affects the exit of a bullet from the cartridge and thus whether the cartridge should be cleaned between the firing and reloading procedure.
- The design of a controllable annealing process for use in a reloading procedure.

Research topics such as these could provide interesting information that may prove useful to high end target shooters and reloaders in general.

13.0 Conclusions & recommendations

The work investigated the use of brass cartridges in a firing-reloading cycle such as is used in high end target shooting by Tim Stewart.

The microscopic examination of the un-etched samples revealed some minor cracks and wall thinning at the base of the cartridge. The neck turning procedure used in the preparation of sample sets C and DCA was found to regularly cut into the shoulder of the cartridge and create a small 'step'. This 'step' acted as a stress raiser from which a crack was sometimes formed. No examples of significant cracking at this position were found but there is a possibility that upon further use the cracks that were observed may enlarge and become more serious.

The examination of the etched samples showed little variation in the microstructure throughout the use of the cartridges. Large variations were found in the grain structure of the neck annealed cartridge samples (sample sets BAA and DCA). In some cases large variations were observed between two sides of the same cartridge sample.

Vickers hardness tests were used to quantify the work hardening of the cartridges during successive firing-reloading cycles. These results showed that the largest increases in hardness were caused by the firing stages and hence the firing process has a much larger effect on the cartridges than the cold work processes used to prepare the cartridges for reloading. The hardness tests emphasized the variability of the annealing process. It also showed that after annealing the hardness of the cartridge neck quickly increased towards where it would be if annealing had not taken place.

13.1 Recommendations

The results achieved allowed a few recommendations to be made for the improvement of the reloading process.

It is thought that the cracking caused by the neck turning of the cartridges could be reduced if the neck turning was not taken so far down the neck of the cartridges. This should avoid the formation of a 'step' at the start of the shoulder of the cartridge and thus reduce the ability for a crack to form at this point. This minor change in the neck turning procedure may help to significantly extend the useful life of the cartridges.

Throughout the investigation it was shown that the neck annealing process produced inconsistent end results. A few solutions could be applied to combat this. The simplest, would be to drop the neck annealing procedure altogether. This would reduce the lifespan of the cartridge but would ensure that all cartridges would exhibit relatively consistent material properties throughout their lifespan. There would obviously be a resultant downside in terms of cost.

A second option would be to continue annealing cartridges as before but to only use the cartridges in competition before the first anneal. After the cartridges have been annealed they could be used as 'practise' cartridges and thus the accuracy of the shot would be less critical. This solution would ensure that the properties of the cartridges are consistent when in competition (where accuracy is most important) and would extend the lifespan of the cartridge by allowing the annealing procedure to be carried out when the cartridges are to be used for practise purposes.

It may be that the most effective solution, allowing reuse in competition, would be to use a more controllable annealing process. A correctly designed annealing procedure could greatly expand the cartridge lifespan by providing optimal annealing results every time. Such a process could make use of induction heating or a suitable alternative that would allow the accurate control of annealing temperature and time.

The results also suggest that if cartridge neck annealing is to be used it should be performed on a regular basis. This is due to the fact that after annealing the

hardness of the material was seen to quickly increase towards where it would have been if annealing had not taken place.

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