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	IN ENGLISH:		IN NORWEGIAN:
a)	Wear	a)	Slitasje
b)	Gun barrel gases	b)	Kruttgasser
c)	Friction	c)	friksjon
d)	Carbon dioxide	d)	Karbondioksid
e)	Water vapour	e)	Vanndamp

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8) ABSTRACT

In this report a study of the gun barrel wear characteristics of three different gunpowders are performed. The three different gunpowders are: Bofors NC 1214 NEXPLO (NEXPLO), BOFORS NC 1214 EURENCO (EURENCO) and PB Clermont 347 (PBC 347). We study the wear both theoretically and experimentally. We find that PBC 347 gives the least wear.

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1 INTRODUCTION

Nammo Raufoss AS is the inventor of the Multipurpose (MP) ammunition concept. The MP technology was developed during the end of the 60s and the first series production started in the beginning of the 70s. Still the product is of great importance for the company's medium calibre division. Large volumes of ammunition are delivered for the armed forces around the world and in Norway.

Gun erosion has been known as an inevitable problem in use of current gun system, although extensive efforts have been made to minimize it in the world. For a more detailed discussion see references [5].

The Armed forces has asked the following question: Which of the gunpowders: Bofors (NEXPLO), Bofors (EURENCO), and PBC 347 gives the least wear of the 12.7 mm gun barrel? The objective of this report is to firmly answer this question.

Gun barrel wear studies focus on different experimental design. The most common design is a erosion bomb (Figure 2.1). By studying the mass loss through a nozzle the gunpowder with the least wear due to gas erosion could be studied.

The problem with this design is that the wear due to friction between the lands and the projectile is not accounted for. It is well known that the lands are more easily worn out than the grooves. The heat flux into the lands due to friction could be quite different since the different gunpowders furnish different types of pressure time relations during a shot.

We have constructed a special experimental design such that both the wear due to friction and gas dynamics is studied in parallel. Also we have modelled the heat transfer into the gun barrel numerically.

2 THE TWO DIFFERENT EXPERIMENTAL SET-UPS FOR THE WEAR STUDIES

The wear is studied by using the traditional erosion bomb and our modified gun barrel. Figure 2.1 shows the erosion bomb. The wear is simply given by the mass loss of the nozzle closest to the gas chamber.

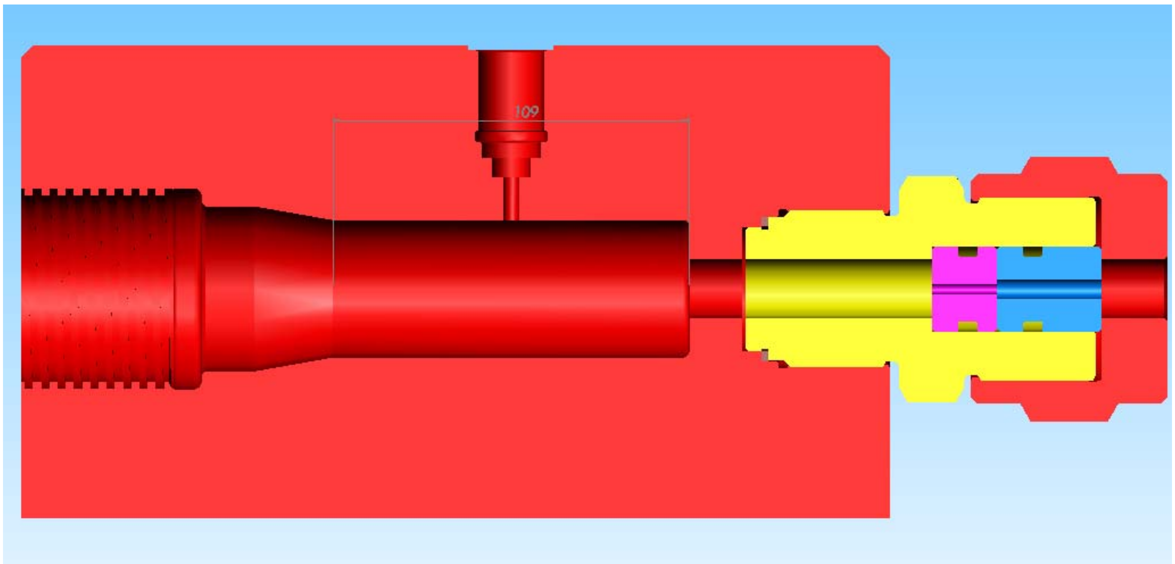

Figure 2.1: The experimental set–up for the erosion bomb test.

Figure 2.2 and Figure 2.3 gives the measured pressure in the erosion bomb. The pressure decreases due to mass flux out of the nozzle.

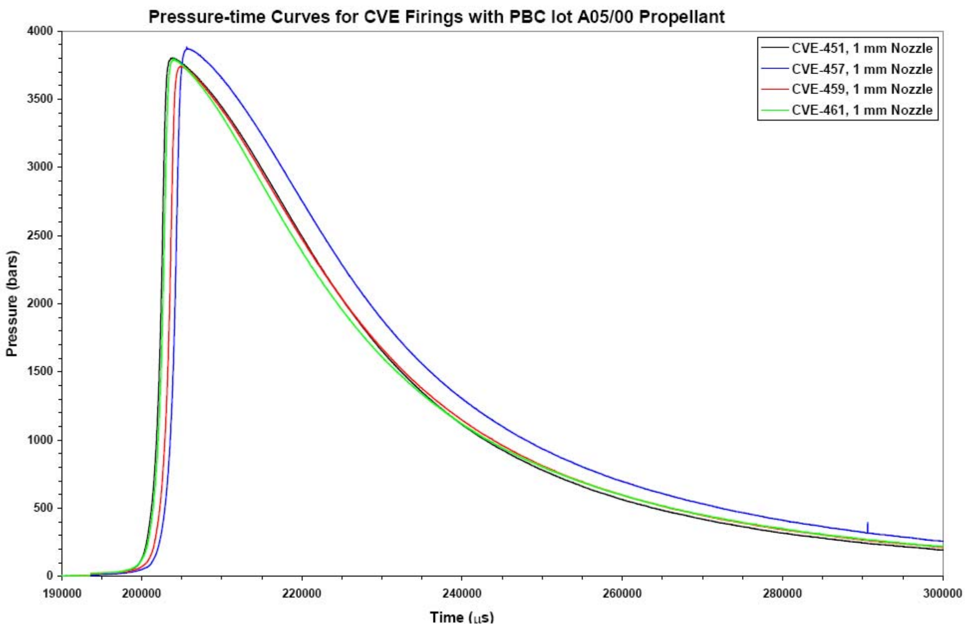

Figure 2.2: The pressure time curve for the PBC 347 gunpowder when firing in an erosion bomb. The mass is 50 grams of gunpowder. [2]

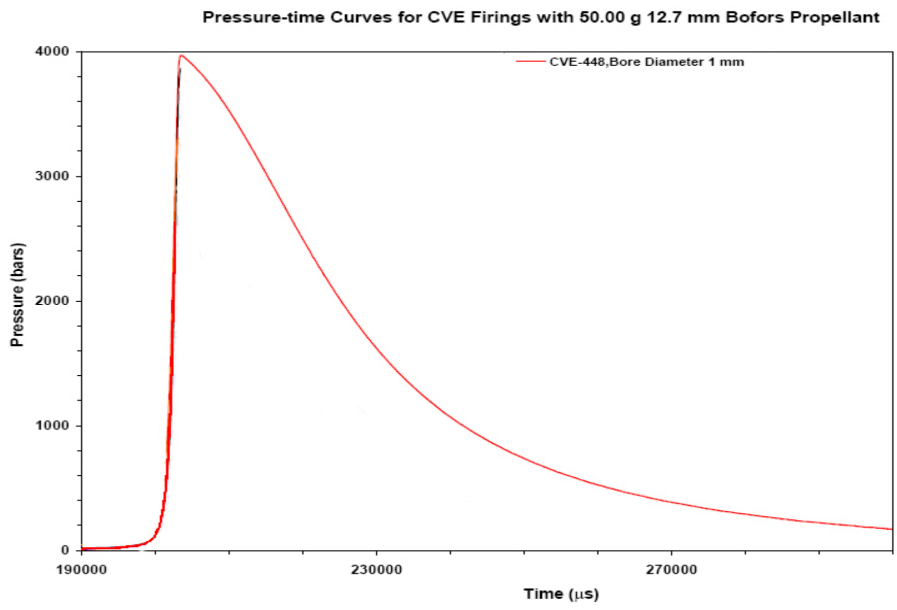

Figure 2.3: The pressure time curve for the NEXPLO gunpowder when firing in an erosion bomb. The mass is 50 grams of gunpowder. [2]

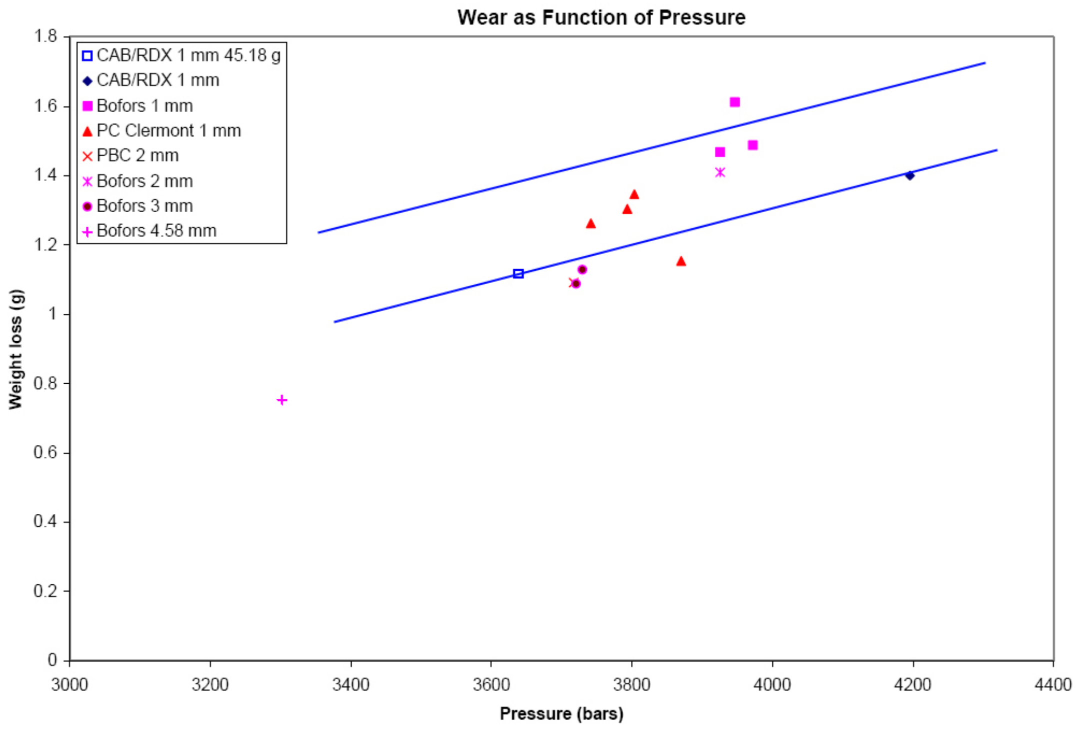

Figure 2.4: The weight loss for the different firings in the erosion bomb. [2]

Figure 2.4 shows the experimental results from reference [2]. We have drawn a straight line through the average point for the PBC 347 and the NEXPLO gunpowder. The line is drawn with an angle to the horizontal axis equal to the angle for the CAB/RDX results where two different loading densities were used.

Figure 2.5 and Figure 2.6 shows the new design for the study of wear in the gun barrel. With this design we can replace the inner section (red section in figure 2.5) of the gun barrel without having to destroy it for every wear test.

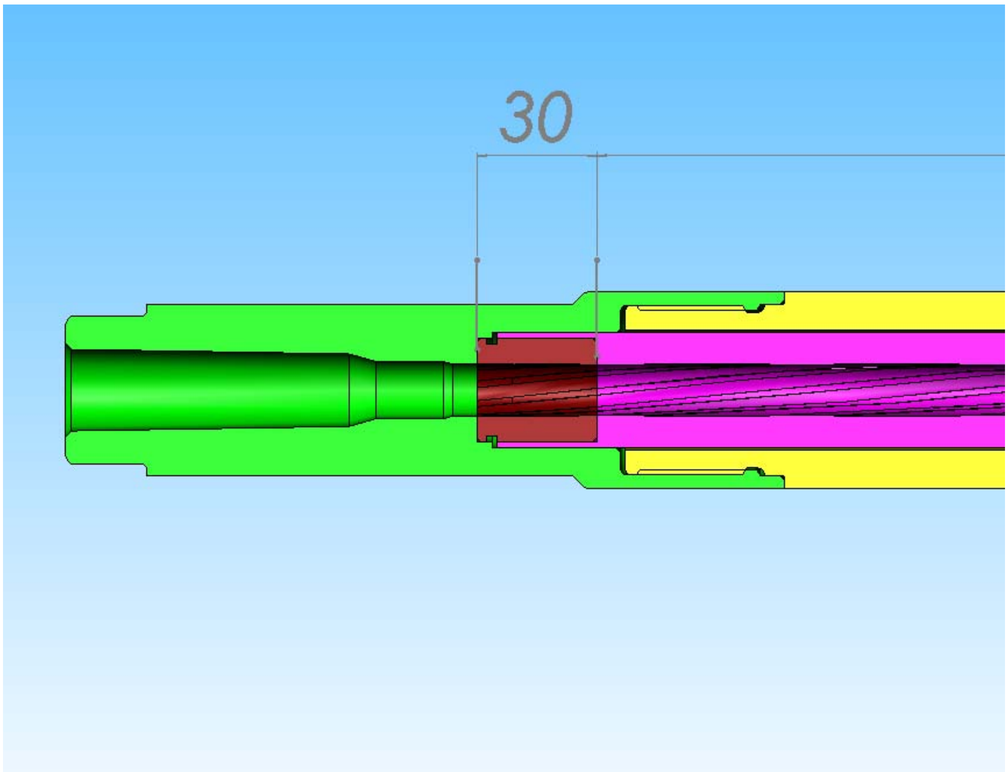

Figure 2.5: The design of the modified gun barrel for studying wear.

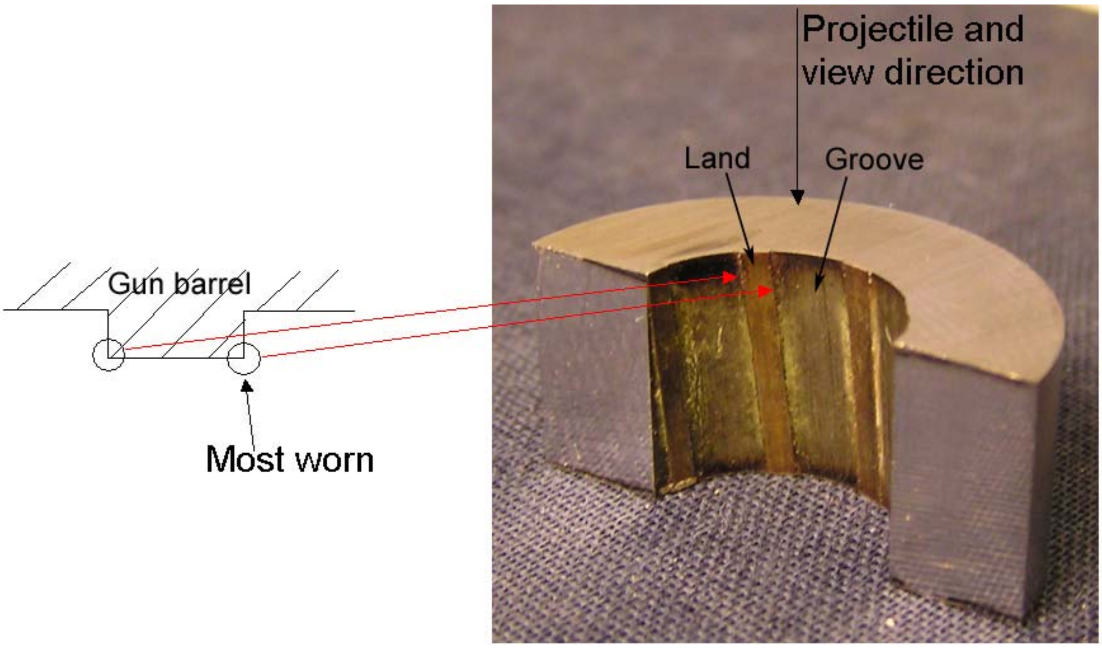

Figure 2.6: A cut out specimen of the gun barrel.

The wear is established by studying the heat-affected zone on the lands of the gun barrel after a number of shots for each of the different gunpowders.

3 THE CHEMICAL COMPOSITION OF THE GUNPOWDER GASES

The chemical composition of the gunpowder gases is given in Figure 3.1 for a typical density during a shot. We do not have the exact certificate for the EURENCO, but we assume that it is not very different from the NEXPLO certificate [1].

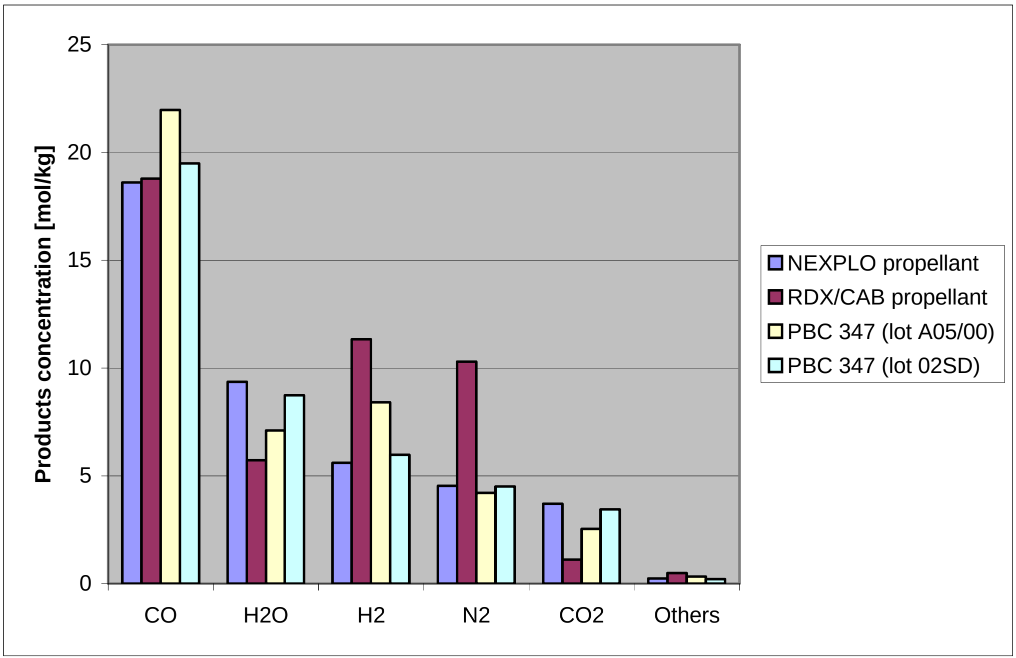

Figure 3.1: All propellants. The density of the gunpowder gas is 0.3 kg/m^3.

The composition of the PBC 347 lot 02SD powder was achieved by using Cheetah calculations [2] for the compositions reported from the certificate (PB Clermont in Belgium). The composition of the lot PBC 347 lot A05/00 was found by curve fitting using the results from the experimental closed bomb analyses. The composition was achieved by changing the amount of Nitroglycerin and Dibutylphtalate from 10.1% to 5% and 6.4% to 10% , respectively. This procedure is somewhat arbitrary and we will study this more closely in later reports.

4 THE EQUATION OF STATE AND THE TEMPERATURE FOR THE GUNPOWDER GASES

The equation of state and the temperature are important relations for the gunpowder gases. Other characteristics of the different gunpowders are given in table 4.1 and 4.2.

	Length [mm]	Inner radius [mm]	Outer radius [mm]	Density of grain [g/cm^3]	Bulk density [g/cm^3]	Heat of combustion (Calorific value) [kJ/kg]	Certificate
Bofors NC1214 (Nexplo)	1.71* 1.88** 1.93***	0.1* 0.08** -	0.69* 0.70** 0.665***	1.60	0.93	3900	Yes
Bofors NC1214 (Eurenco)	2.00* 1.82***	0.1* -	0.7* 0.745***	-	0.955	3900	Yes, partially
PBC 347 lot A05/00 Spherical	-	-	-	-	-	-	No
PBC 347 lot 02SD Spherical	-	-	Sieved (0.25-0.5)	1.57	0.99	3600	Yes
PBC 347 lot 38/04 Spherical	-	-	0.42***	-	-	-	No

*Table 4.1: Some characteristics of gunpowder. * : given from manufacturer, **: measured by FFI(Nevstad) *** measured by FFI(Frøyland)..*

	Impetus [J/gram] measured	Impetus* [J/gram] (Cheetah calculation)	Co volume [cm^3/gram] measured	Co volume* [cm^3/gram] (Cheetah calculation)	Burning velocity (rate) [cm/sec] p: pressure [bar]	Equation of state $p/\rho = a\,p + b$ [J/gram]
Bofors NC1214 (Nexplo) Cylindrical	1004	1017	0.9	0.98	$0.002\ p^{1.24}$** ($0.003\ p^{1.18}$***)	a=covolume b=impetus
Bofors NC1214 (Eurenco)	-	-	-	-	-	a=covolume b=impetus
PBC 347 lot A05/00 Spherical	901	919 (changed content)	0.98	1.03 (changed content)	$0.0004\ p^{1.39}$***	a=covolume b=impetus
PBC 347 lot 02SD Spherical	-------	1010	-------	0.99		a=covolume b=impetus

Table 4.2: Some characteristic properties of different gunpowders.:load density 0.3 kg/m^3 **: calculated by FFI(Nevstad) [1] ***: calculated by FFI(Frøyland).*

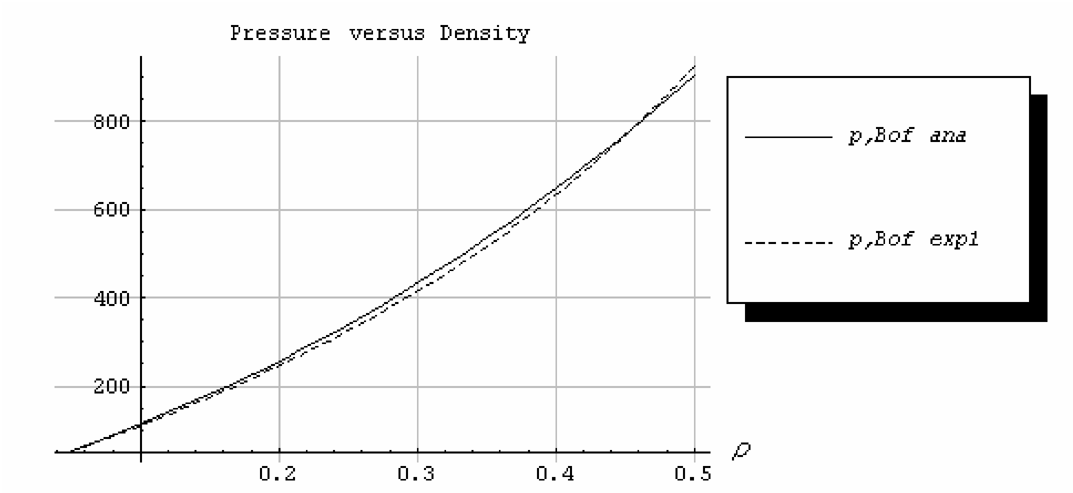

Figure 4.1: The experimental and analytical gas pressure in MPa as a function of the loading density in gram/cm^3 (NEXPLO). Analytical results are based on Cheetah calculations [1].

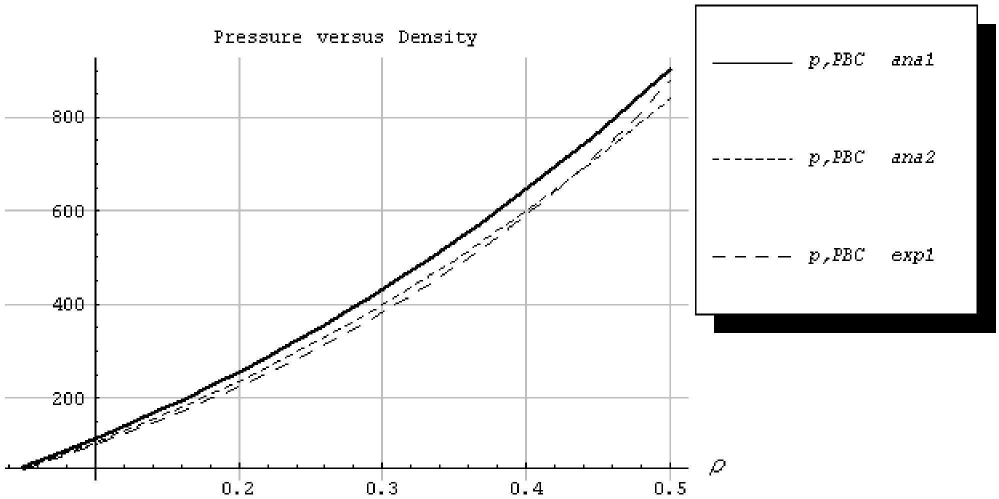

Figure 4.2: The experimental and analytical gas pressure in MPa as a function of the loading density in gram/cm^3 (PBC 347). Analytical results are based on Cheetah calculations [2]. ana1= PBC 347 lot 02SD according to the certificate, ana2= PBC 347 lot A05/00, exp1=PBC 347 lot A05/00.

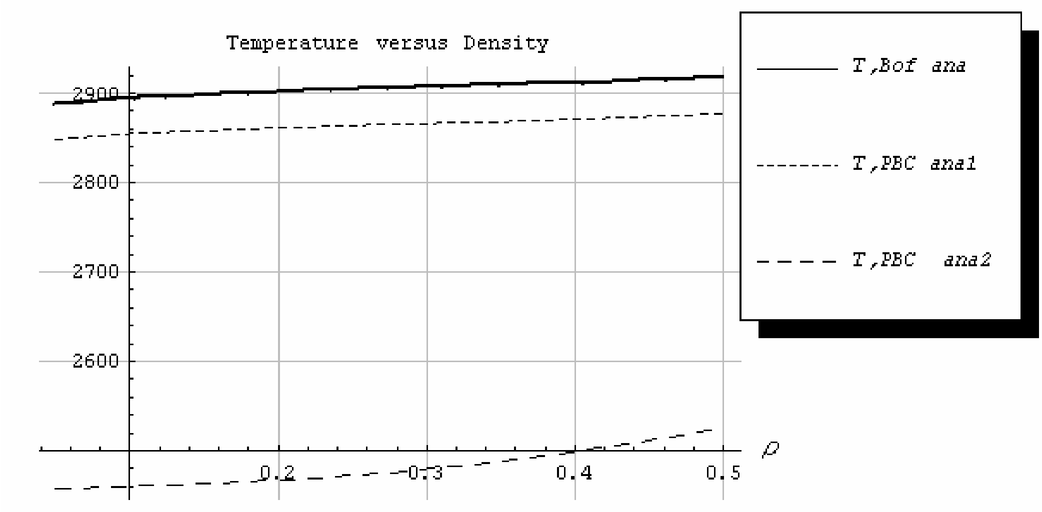

Figure 4.3: The temperature of the gun power gases in Kelvin as a function of loading density in gram/cm^3. Analytical results are based on Cheetah calculations [1,2]. Bof= NEXPLO. ana1= PBC 347 lot 02SD according to certificate, ana2= PBC 347 lot A05/00.

Figure 4.3 shows that the PBC 347 lot A05/00 gives a much lower temperature than the NEXPLO gun power. The results are significantly different from the NEXPLO results or the PBC 347 lot 02SD results. Based on this we do not believe that the suggested change in the Nirtoglycerin and Dibutylphtalate is a reasonable explanation for the difference between PBC 347 lot A05/00 and PBC 347 lot 02SD [2].

By comparing the pressure in Figure 4.1 with the pressure in Figure 4.2 we find that for a given loading density the NEXPLO gives larger pressure than the PBC 347. The actual maximum pressure during a shot or during an erosion test is dependent of the geometrical form of the gun powder and the burning velocity of the powder.

5 THE BURNING VELOCITY OF THE DIFFERENT GUNPOWDERS

The results from the burning velocity analysis are shown in Figure 5.1. It is found that NEXPLO gives a higher burning velocity than PBC 347.

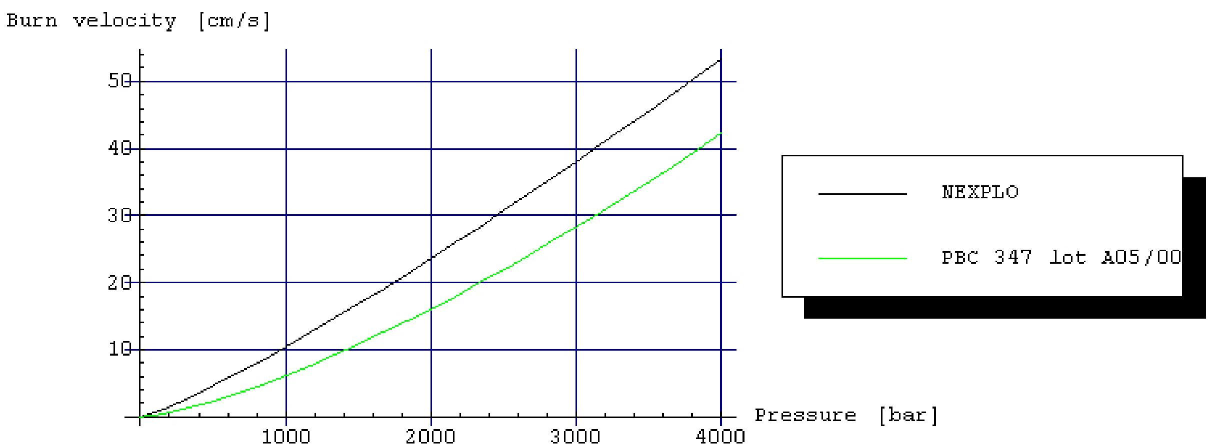

Figure 5.1: The burning velocity of the gunpowders as a function of pressure.

6 THE PRESSURE OF THE GUNPOWDER GASES AS A FUNCTION OF TIME DURING A SHOT

We have used our ballistics code to find the pressure as a function of time during a shot [6]. Input for the calculations are the projectile mass, the geometrical form of the gunpowder, the equation of state for the gunpowder and the burning velocity of the gunpowder as a function of the pressure. Figure 6.1 shows the results.

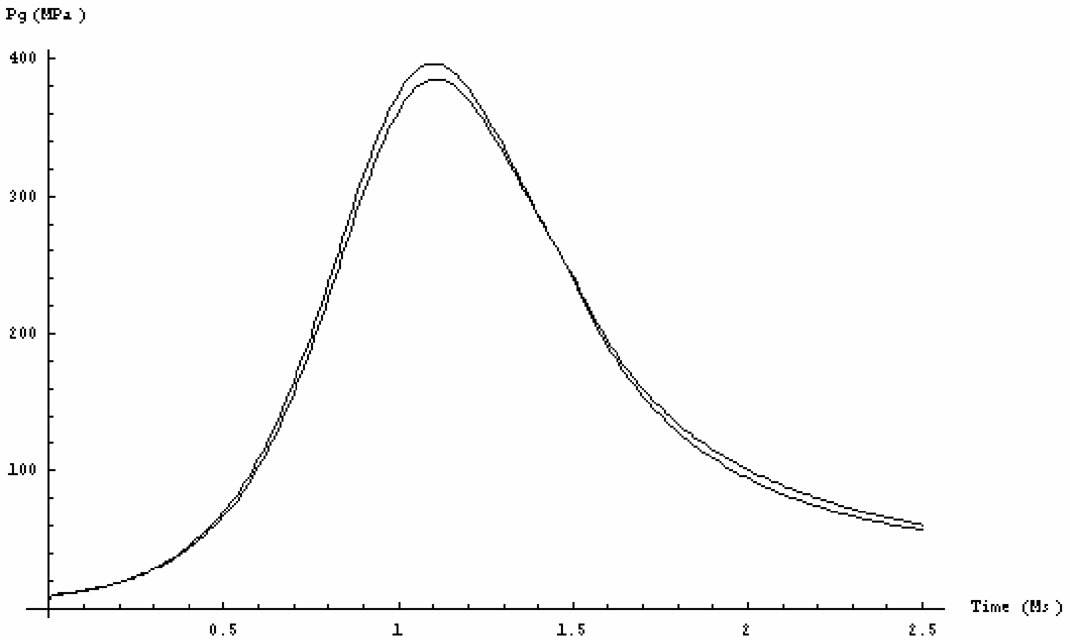

Figure 6.1: The pressure during a shot as a function of time for NEXPLO and PBC 347.

We find that during a shot the area under the pressure-time curve and the peak pressure of the pressure curve are almost the same for the two different gunpowders. During a shot the exit velocity is 20-30 m/s higher for the NEXPLO compared to the PBC 347.

7 THE TEMPERATURE IN THE GUN BARREL AS FUNCTION OF TIME AND POSITION FOR DIFFERENT GUNPOWDER GASES

The temperature rise of the gun barrel is dependent of the position in the barrel. The main heat transfer is due to convection and not radiation.

Figures 7.1-7.2 show the temperature of the inside surface of the gun barrel [3]. It is assumed that the velocity of the gun barrel gases increases linearly from the bottom of the cartridge up to the projectile. For any point along the gun barrel axis, the heat transfer starts when the rear of the projectile reaches that position. The heat transfer function as a function of time is rather complex since the density of the gases increases as a function of time in the beginning due to the burning of the gunpowder.

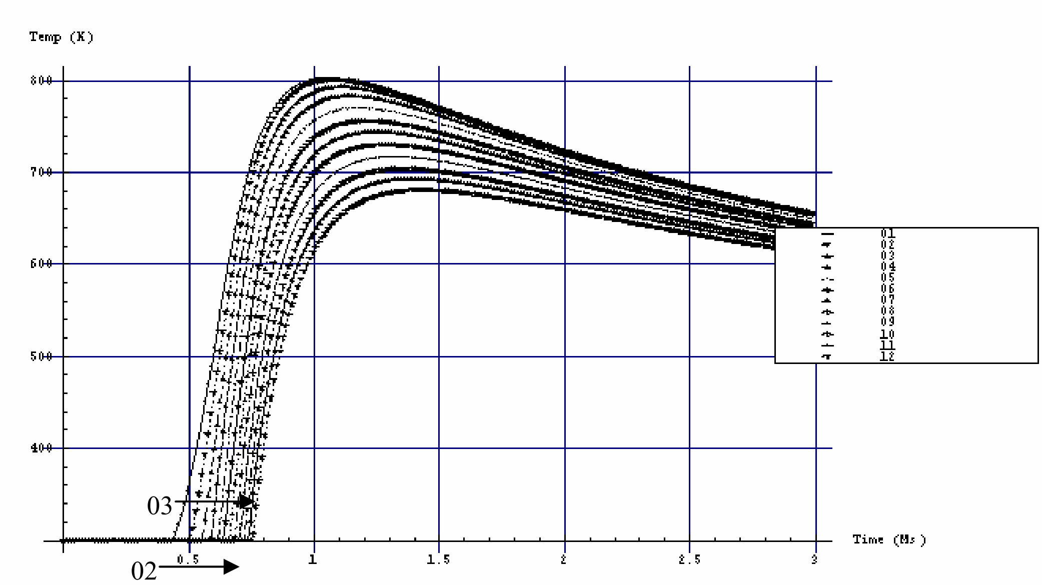

Figure 7.1: The temperature at the inside surface of the gun barrel for different positions along the gun barrel using the NEXPLO. The first point corresponds with the rear of the projectile. The velocity is zero at the bottom of the cartridge and is increasing linearly up to the projectile velocity.

Observe that the temperature decreases along the gun barrel while the peak of the heat flux reaches a maximum for approximately 10 cm along the gun barrel. The distance is measured from the base position of the projectile. Figure 7.2 gives the results for the PBC 347 powder.

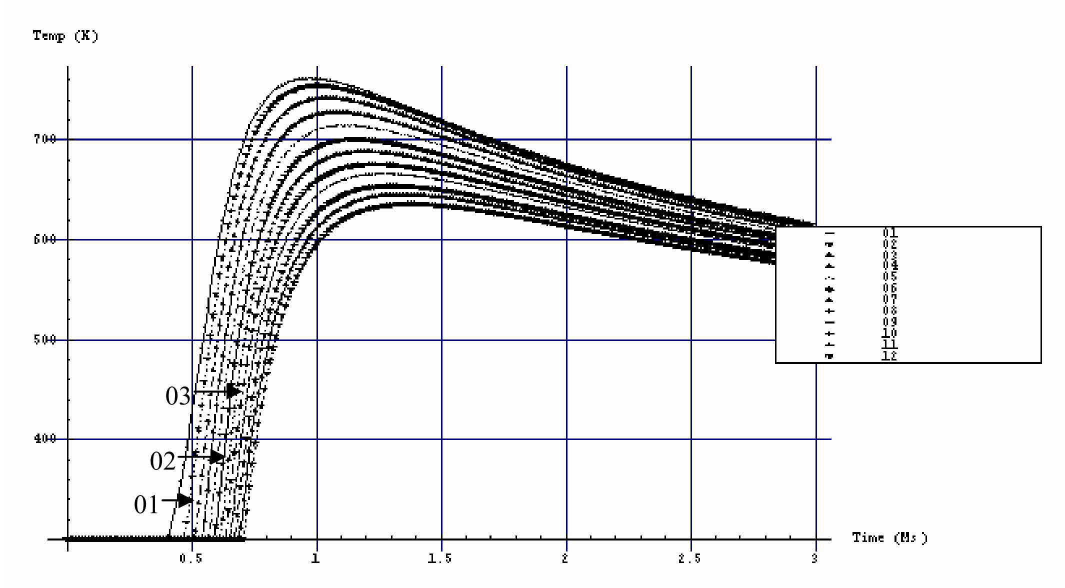

Figure 7.2: The temperature as a function of time along the inside surface of the gun barrel for PBC 347 gunpowder.

The erosion per shot is given by the empirical formulae [7]

$$erosion = A\,Exp[\,(T_{max} - 273)/69],\, A \in \left(10^{-7}\,\mu m, 4\,10^{-6}\,\mu m\right) \tag{7.1}$$

Thus the gunpowders give

$$A\,Exp[\,(T_{max} - 273)/69] = \begin{cases} A\,1162, when, T_{max} = 760K, PBC\,347, \\ A\,2075, when, T_{max} = 800K, NEXPLO \end{cases} \tag{7.2}$$

This gives a factor of (1162/2075)= 0.6 in fractional difference between the gunpowders.

8 EXPERIMENTAL RESULTS

The new gun barrel design (Figure 2.5) was used to study the erosion in a gun barrel. The mass of gunpowder was chosen such that the projectile exits the gun barrel with approximately the same velocity (~800 m/s). This gave the following gunpowder masses. NEXPLO:13.60 grams, EURENCO: 15.46 grams, PBC 347 (lot 38/04): 14.03 grams.

The thickness of the lands of an unused gun barrel was measured. It was found significant spread in the thickness of the lands for the specimen from gun barrel no. 2.

Gun barrel no. 1 - unused		
	Thickness of lands [µm]	
Land no.	Left	Right
1	111	109
2	113	103
3	120	102
4	124	94
5	105	102
6	114	109
Average	115	103
Std. dev.	7	6

Gun barrel no. 2 - unused		
	Thickness of lands [µm]	
Land no.	Left	Right
1	164	159
2	132	149
3	83	70
4	98	90
5	102	106
6	83	105
7	129	114
8	156	142
Average	118	117
Std. dev.	32	31

Table 8.1: The thickness of the lands of two unused gun barrels.

The probability that the mean difference between the thickness of the lands of the unused gun barrel no. 1 and the unused gun barrel no. 2 is zero is found to be 28% (Two-sided student t-distribution with unknown variance). The probability that the variance ratio is 1 for the thickness of the lands for the unused gun barrel no. 1 and the unused gun barrel no. 2 is 0.01%. This indicates that the two unused gun barrels are indeed different!

Next we analysed the gun barrels after 20-30 shots. Figure 8.1 shows a typical example of unused gun barrel (no. 2), while figure 8.2 shows a typical result after firing 20 shots. We do not find significant wear of the lands, but cracks and heat affected zones are clearly seen. Figure 8.3 and Figure 8.4 shows the results for gun barrel no. 1. The results are the same as for gun barrel no. 2. The results are summarized in Table 8.2.

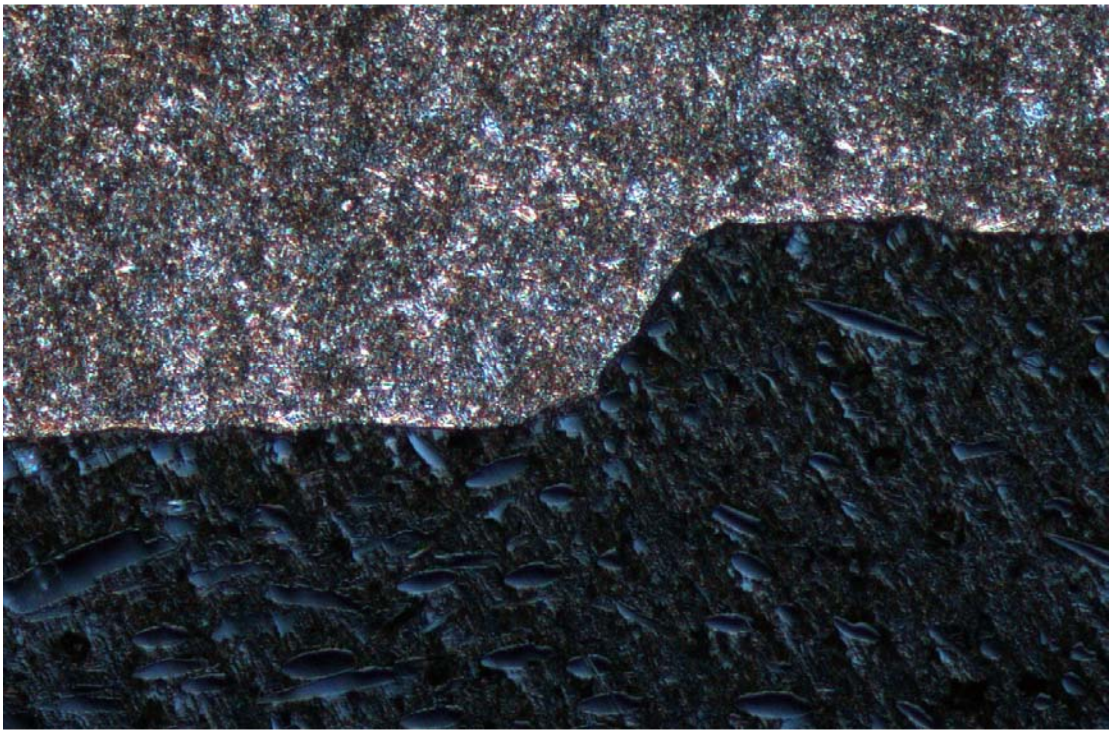

Figure 8.1: Unused gun barrel no. 2.

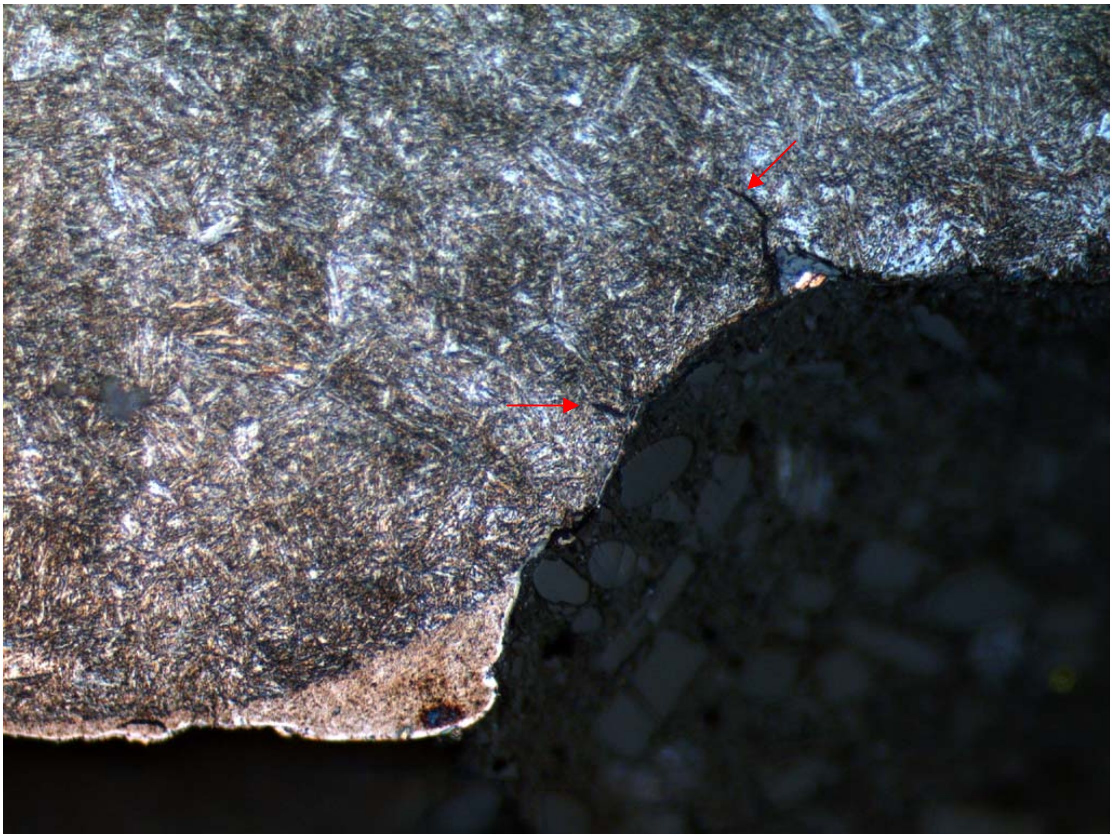

Figure 8.2: Gun barrel no. 2 after 20 shots (NEXPLO).

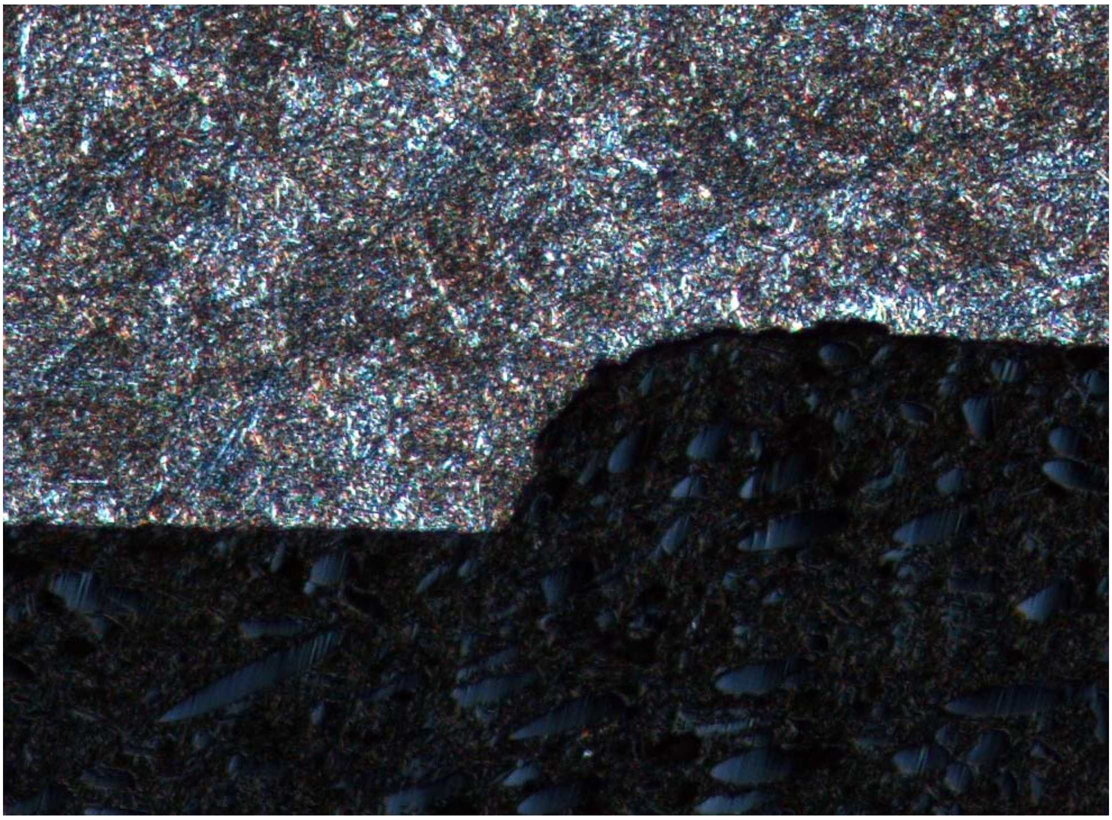

Figure 8.3: Unused gun barrel no. 1.

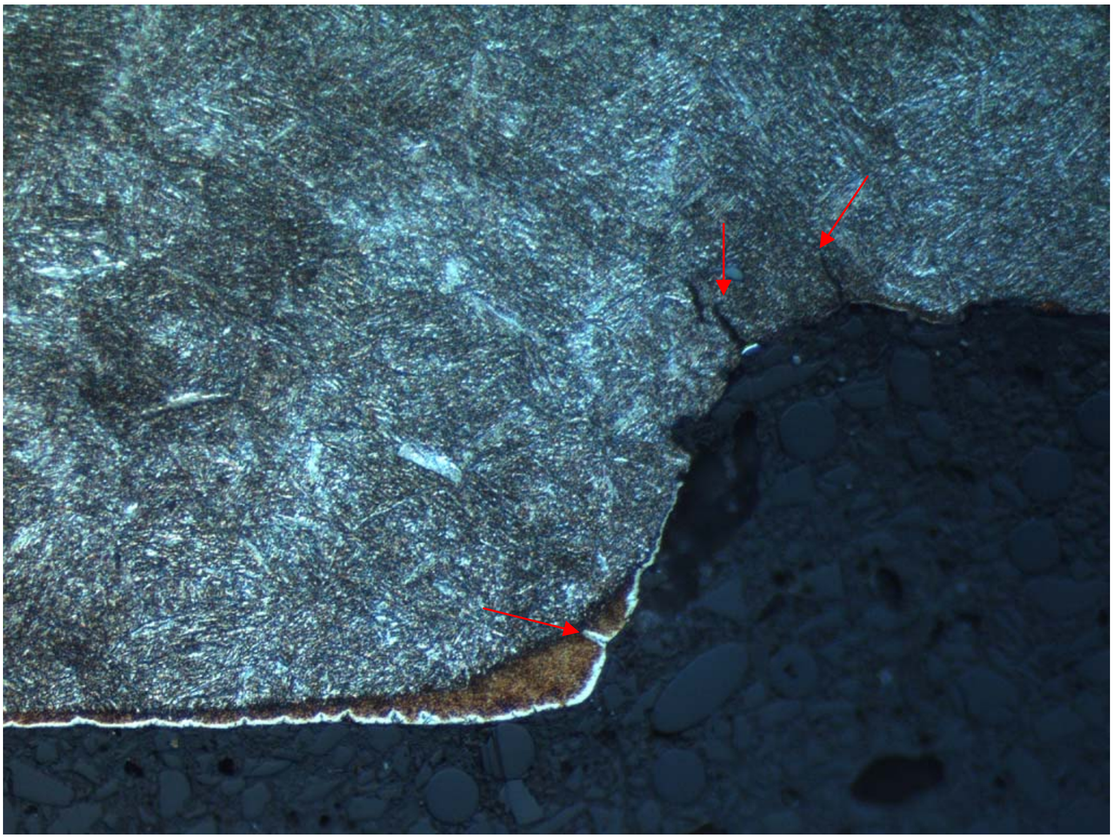

Figure 8.4: Gun barrel no. 1 after 28 shots (EURENCO).

Unused - gun barrel no. 1		
	Thickness of lands [µm]	
Land no.	Left side	Right side
1	111	109
2	113	103
3	120	102
4	124	94
5	105	102
6	114	109
Average	115	103
Std. dev.	7	6

Projectile: MP inert - Gunpowder: Bofors Nexplo - 25 shots - gun barrel no. 1		
	Thickness of lands [µm]	
Land no.	Left side	Right side
1	105	102
2	118	111
3	113	113
4	122	116
5	105	102
Average	113	109
Std. dev.	8	6

Unused - gun barrel no. 2 - specimen 2		
	Thickness of lands [µm]	
Land no.	Left side	Right side
1	164	159
2	132	149
3	83	70
4	98	90
5	102	106
6	83	105
7	129	114
8	156	142
Average	118	117
Std. dev.	32	31

Projectile: MP inert - Gunpowder: Bofors EURENCO - 20 shots - gun barrel no. 2		
	Thickness of lands [µm]	
Land no.	Left side	Right side
1	157	152
2	146	153
3	107	122
4	55	74
5	111	98
Average	115	120
Std. dev.	40	34

Table 8.2: The thickness of lands for unused and used gun barrels.

Figures 8.5-8.10 show the typical results for the different gunpowders. A heat affected zone is clearly visible. Table 8.3 shows the measured thickness of the heat affected zone. Figure 8.11 gives a graphical summary of the average thickness of the heat affected zones. PBC 347 gives the least heat affected zone. NEXPLO and EURENCO give approximately the same heat affected zone.

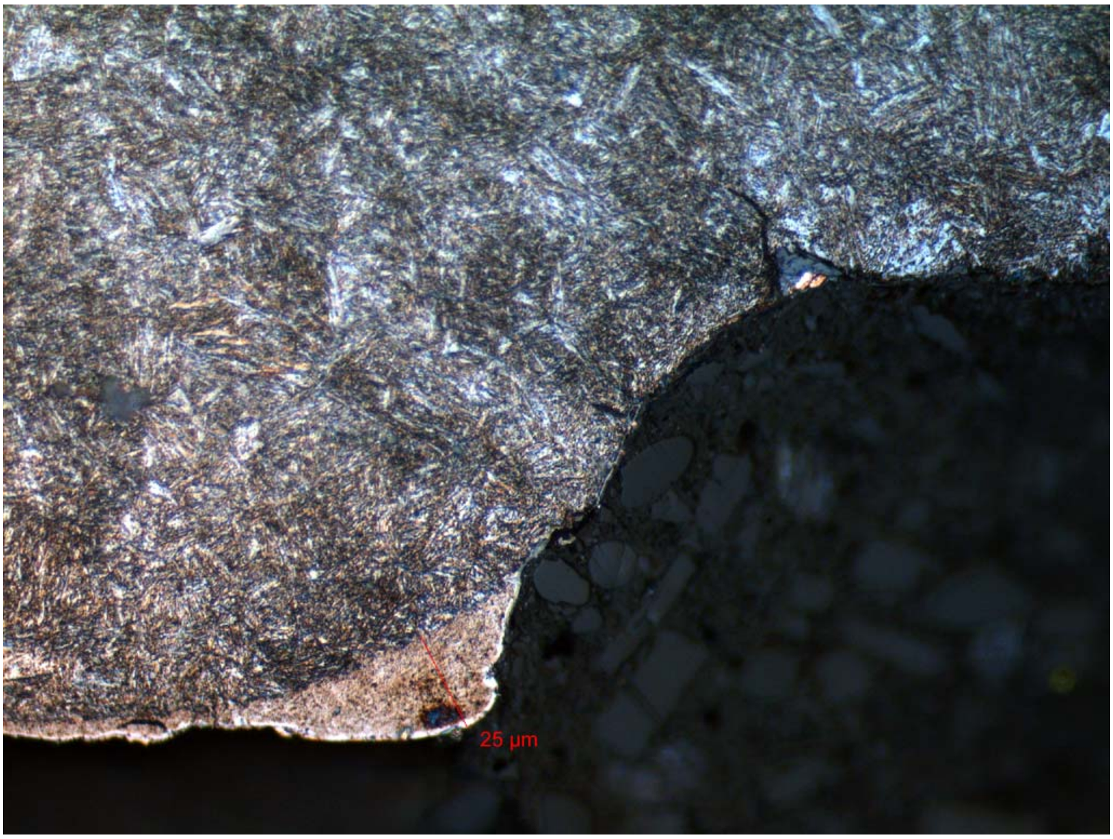

Figure 8.5: The gun barrel no. 2 after 20 shots for NEXPLO (right side of land).

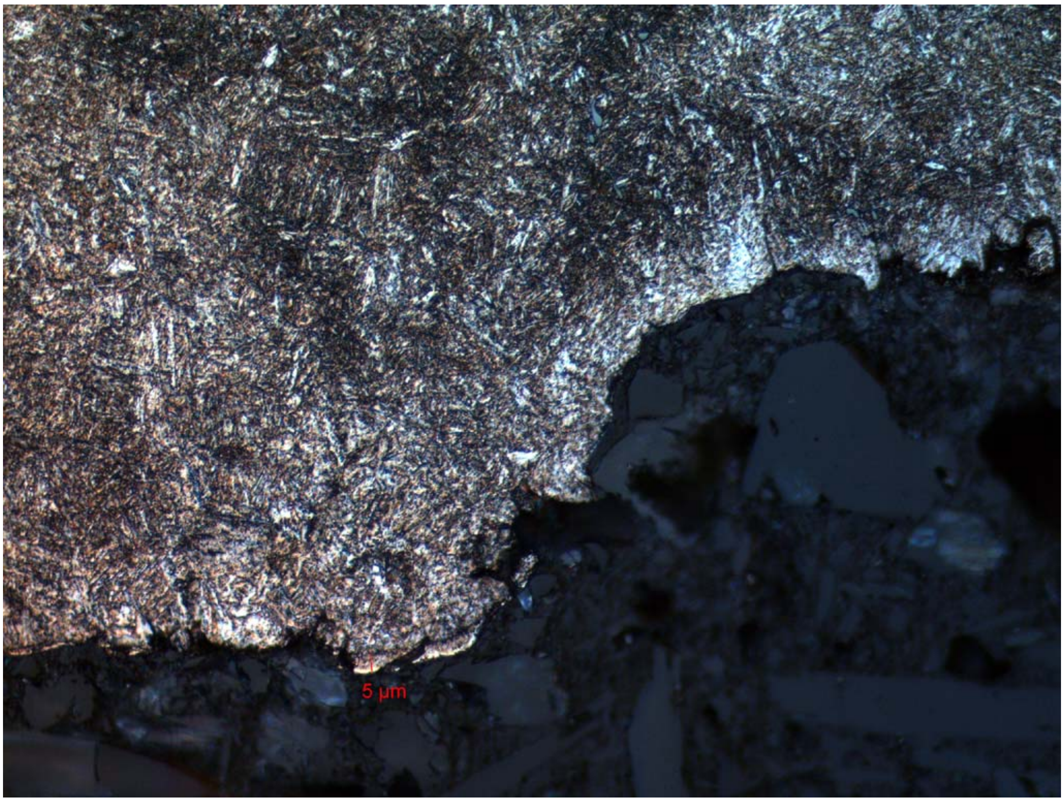

Figure 8.6: The gun barrel no. 2 after 20 shots for PBC-347 lot 38/04 (right side of land).

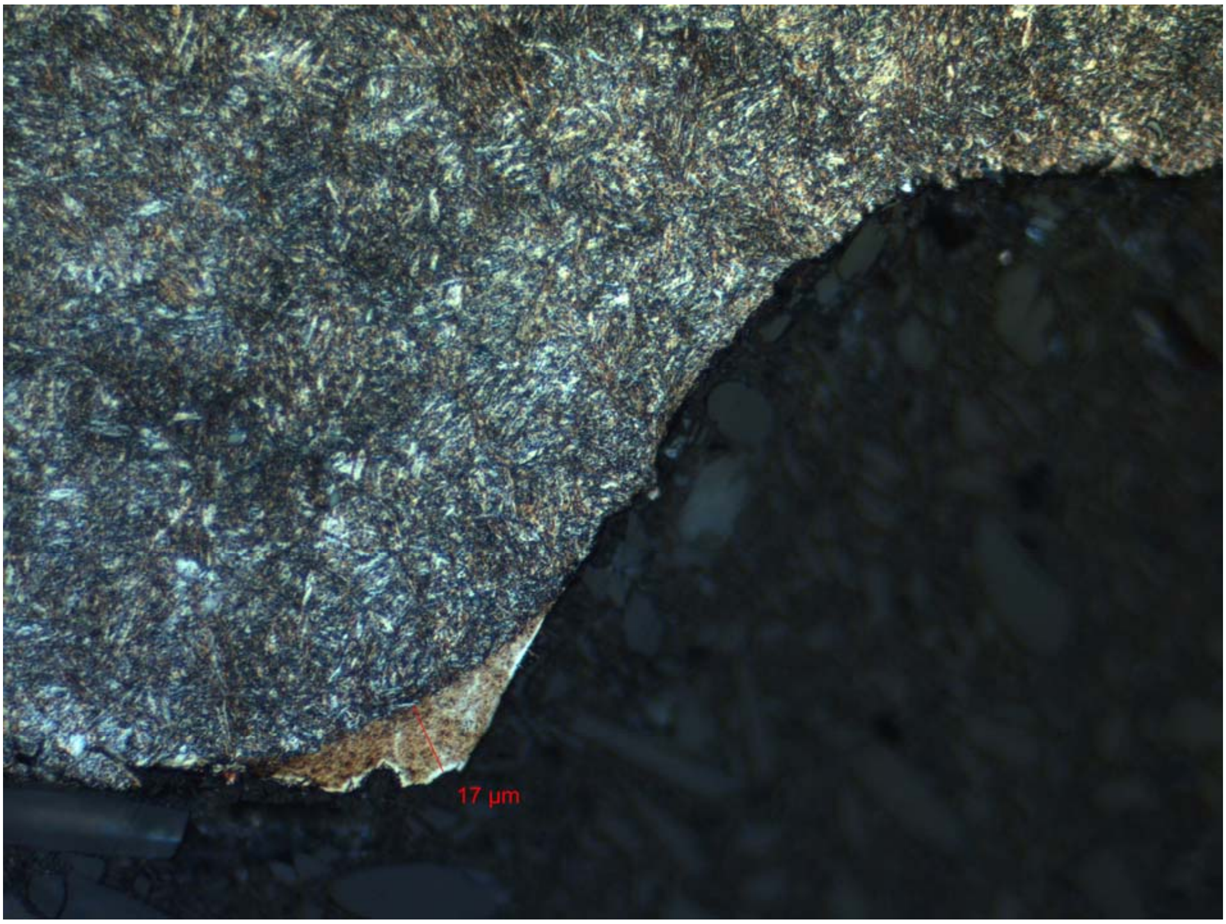

Figure 8.7: The gun barrel no. 2 after 20 shots for EURENCO (right side of land).

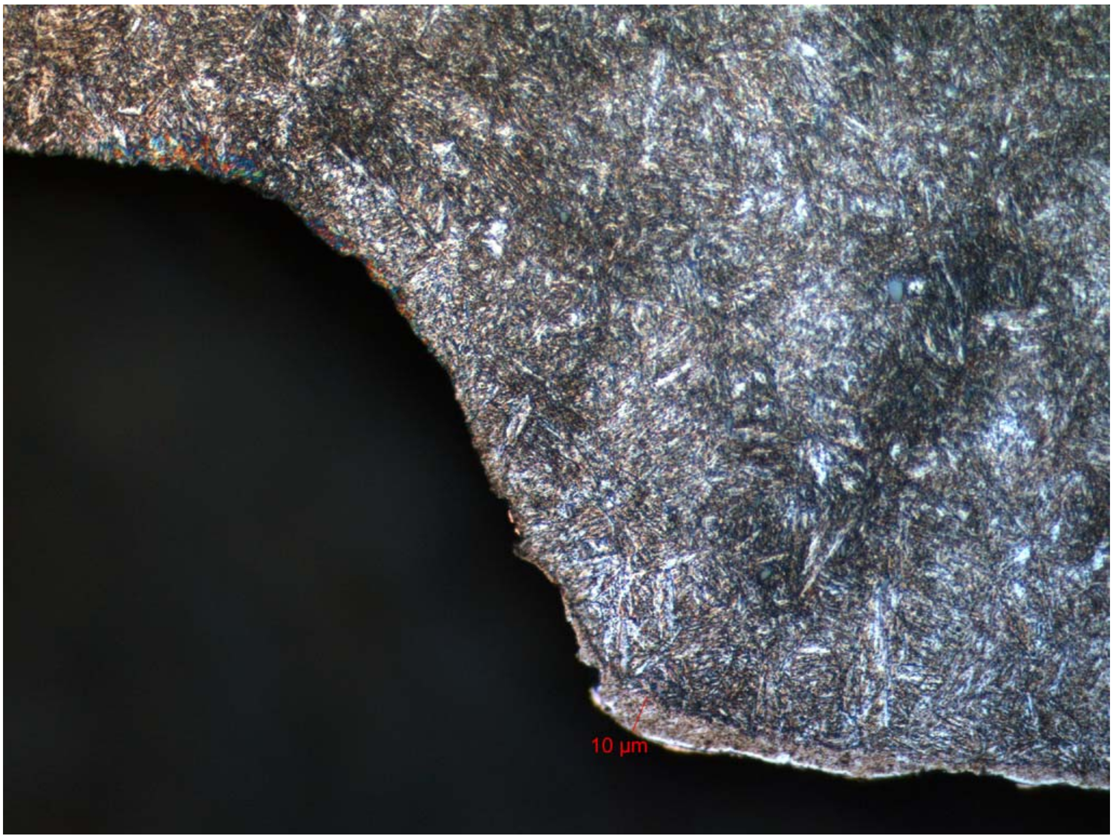

Figure 8.8: The gun barrel no. 2 after 20 shots for NEXPLO (left side of land).

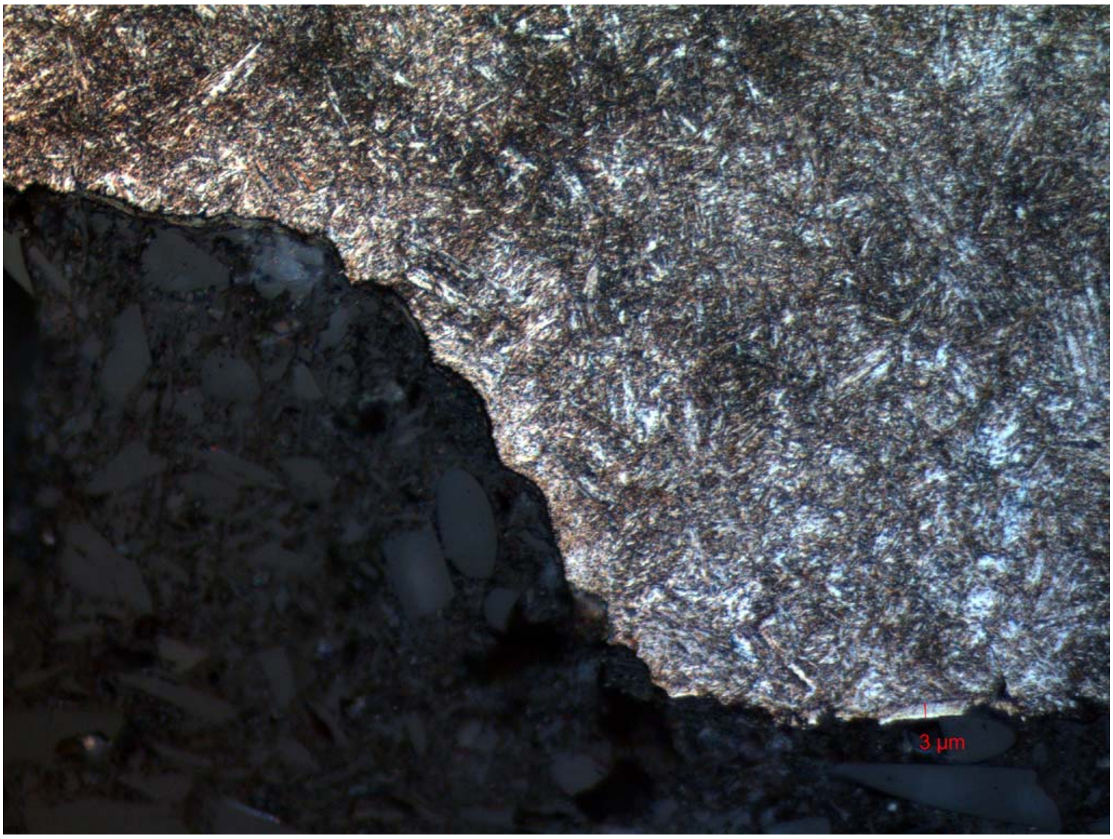

Figure 8.9: The gun barrel no. 2 after 20 shots for PBC-347 lot 38/04 (left side of land).

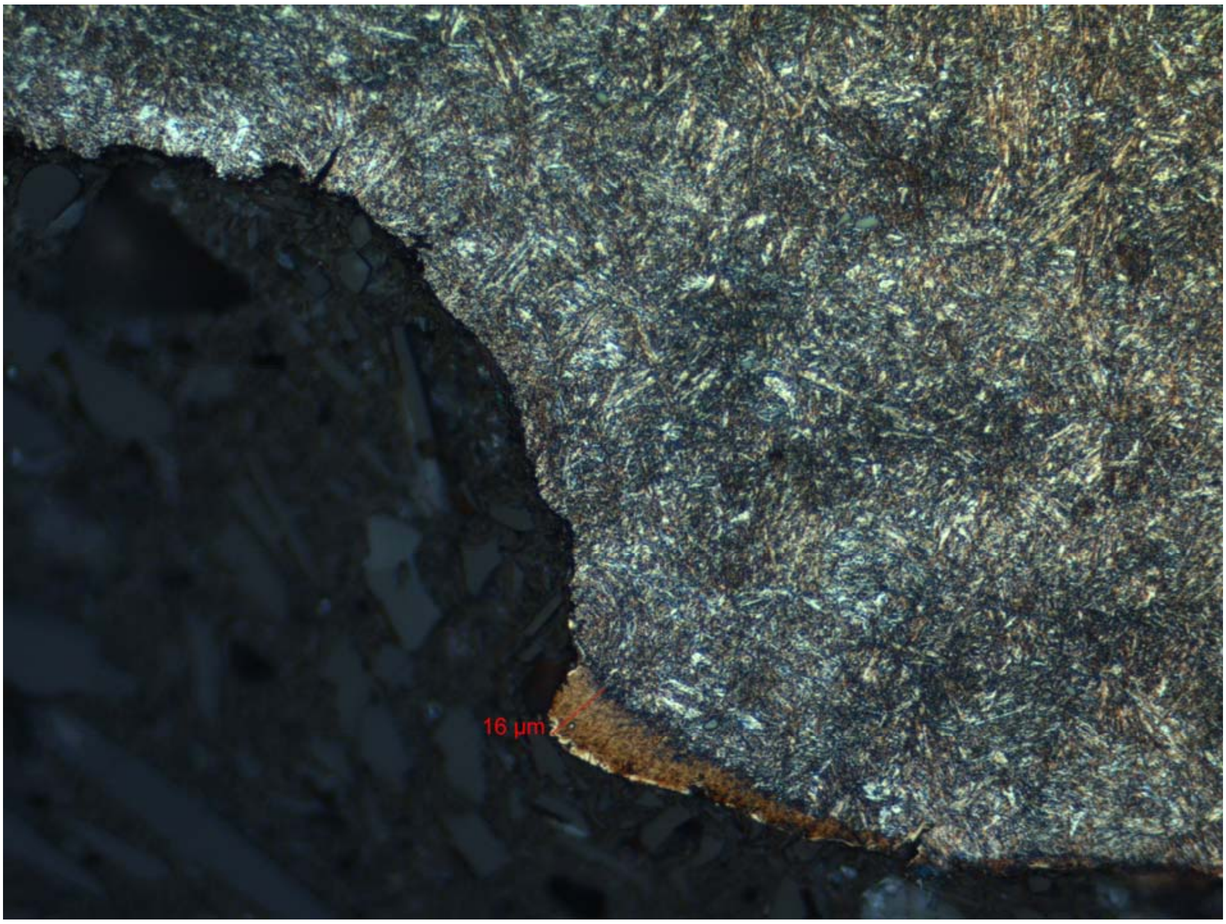

Figure 8.10: The gun barrel no. 2 after 20 shots for EURENCO (left side of land).

Projectile: MP inert - Gunpowder: Bofors EURENCO - 20 shots - gun barrel no. 2		
	HAZ thickness [µm]	
	Left	Right
1	10	25
2	16	17
3	10	11
4	6	12
5	12	18
Average	11	17
Std. dev.	4	6

Projectile: MP inert - Gunpowder: Bofors NEXPLO - 20 shots - gun barrel no. 2		
	HAZ thickness [µm]	
	Left	Right
1	12	25
2	10	27
3	12	12
4	9	7
5	0	9
Average	9	16
Std. dev.	5	9

Projectile: MP inert - Gunpowder: PBC 347 - 20 shots - gun barrel no. 2		
	HAZ thickness [µm]	
	Left	Right
1	3	5
2	7	11
3	6	9
4	0	0
5	4	3
Average	4	6
Std. dev.	3	4

Table 8.3: The thickness of the heat affected zone (HAZ) for different gun powders.

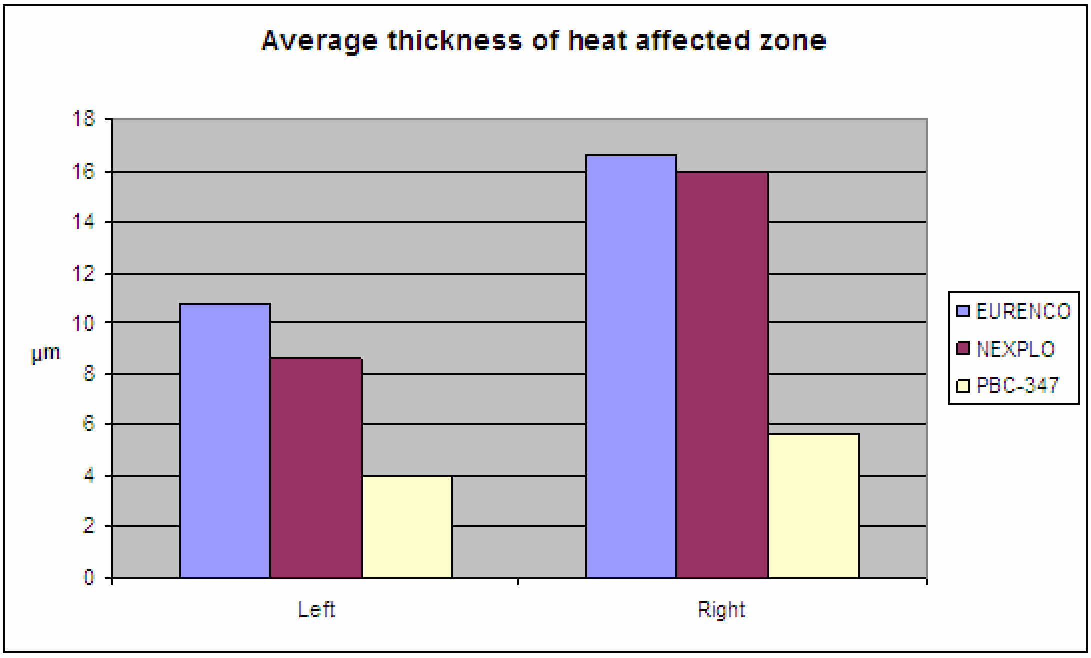

Figure 8.11: The heat affected zone for different gun powders.

8.1 Wilcoxon's rangsumtest

We have performed a statistical test called the Wilcoxon's rangsumtest [4]. This test is used for populations that are not assumed to be a normal distribution. We want to test whether PBC 347 has less thickness of the heat affected zone then NEXPLO and EURENCO.

The hypothesis are:

H_0: Expected thicknesses of heat affected zones are equal

H_0 is not accepted if $T<T_l$ or $T>T_r$.

For a 5 % significance level T_l=17 and T_r=38:

EURENCO Left		**PBC 347** Left	
Rangnumber, T	HAZ thickness [µm]	Rangnumber, T	HAZ thickness [µm]
8	10	2	3
10	16	6	7
7	10	5	6
4	6	1	0
9	12	3	4
38		17	

H_0 is accepted.

EURENCO Right		**PBC 347** Right	
Rangnumber, T	HAZ thickness [µm]	Rangnumber, T	HAZ thickness [µm]
10	25	3	5
8	17	6	11
5	11	4	9
7	12	1	0
9	18	2	3
39		16	

H_0 is not accepted

NEXPLO Left		**PBC 347** Left	
Rangnumber, T	HAZ thickness [µm]	Rangnumber, T	HAZ thickness [µm]
9	12	3	3
8	10	6	7
10	12	5	6
7	9	1	0
2	0	4	4
36		19	

H_0 is accepted

NEXPLO Right		PBC 347 Right	
Rangnumber, T	HAZ thickness [µm]	Rangnumber, T	HAZ thickness [µm]
9	25	3	5
10	27	7	11
8	12	5	9
4	7	1	0
6	9	2	3
37		18	

H_0 is accepted

Thus by using this test we have a 95 % probability that the PBC 347 is different and better than the EURENCO gunpowder for one of the situations.

8.2 Welch's approximate t-test

We have also done a Welch's approximate t-test (similar to Student's t-test but with differing variances for the populations). The hypothesis is the following:
H_0: Expected thicknesses of heat affected zones are equal

We use a one-sided test since we expect PBC 347 to give a smaller thickness of the heat affected zone. The H_0 hypothesis will be rejected for a signficance level of 5%.
By using the sofware Mathematica we find that:

Eurenco vs. PBC-347, left side:
Probability (H_0)= 0.6 %.

Eurenco vs. PBC-347, right side:
Probability (H_0)= 0.5 %.

Nexplo vs. PBC-347, left side:
Probability (H_0)= 5.9 %.

Nexplo vs. PBC-347, right side:
Probability (H_0)= 3.4 %.

Thus for 3 out of 4 cases the H_0 hypothesis is rejected.

9 CONCLUSION

We have found that the PB Clermont (PBC 347) gunpowder gives less wear than the Bofors (NEXPLO and EURENCO) gunpowders. Our results were found by using a new gun barrel design for wear studies. Our results are in agreement with earlier gun barrel erosion studies. In general we find that the new modified gun barrel design constitutes a powerful tool for gun barrel wear studies.

References

[1] Nevstad, G. O., "Interior ballistic properties of 12.7 mm MP ammunition", FFI/Rapport-2002/00022
[2] Nevstad, G. O., "Testing of gun barrel erosion by erosion bomb", FFI/Rapport-2003/00345
[3] Frøyland, Ø., Moxnes, J. F., "Gun barrel wear studies based on physical kinetics", FFI/Rapport-2005/03822
[4] Vännman, K., "Matematisk statistikk", 2. opplag 1993, ISBN 82-00-03692-8
[5] Moxnes, J. F., Frøyland Ø., "Friction studies related to wear of gun barrels", FFI/Rapport-2005/01919
[6] Moxnes, J. F., "A model of internal ballistics properties in gun tubes", FFI/Rapport-2002/02385
[7] Lawton, B., "Thermo-chemical erosion in gun barrels", Wear 251 (2001), pp. 827-838