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NEW MATERIALS FOR LARGE-CALIBER ROTATING BANDS FOR HIGH CHARGES

M. Schupfer[1], K. Steinhoff[2], R. Röthlisberger[1]

[1] *Swiss Ammunition Enterprise Corp., Research & Development, 6460 Altdorf, Switzerland*
[2] *Technical University Delft – Department of Production Engineering, 2628 Delft, Netherlands*

Recent increase in the ballistic performance of high loads identified the rotating band as the weakest link in the ballistic system. Finite Element Analysis of the stress distribution in the rotating band and metallographic analysis of fired copper bands revealed the need for new materials. Three alternative materials nickel, titanium and Carbon Fiber Reinforced Composite (CFC) were investigated as substitution of the state of the art copper rotating band because of their mechanical and physical properties. Due to their physical properties, new processes for joining the band on the projectile had to be developed. For nickel, a new welding process especially designed for thin wall carrier projectiles was developed. As it was neither possible to weld titanium nor CFC on the projectiles, new mechanical joining processes were developed. The titanium band was joined by mechanical force through a press, while the CFC was applied by a thermal shrinkage process. Beside the development of new joining technologies for each material, the ballistic experiments showed, that all three different materials are possible substitutions for copper rotating bands.

1. INTRODUCTION

Results of past studies have shown the necessity of finding new rotating band materials for large caliber projectiles with higher physical properties [1, 2]. In those studies it became evident that current rotating bands, particularly in the case of high charges, displayed limits as regards the resistance to heat and in the area of the ductile sealing behavior. Also structural problems at rotating bands were reported in different studies [1]. The goal of the current task, therefore, was to find possible future material alternatives for rotating bands which have the potential in solving the actual problems.

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2. DEMANDS ON THE MATERIAL

2.1 Temperature Gradient Of A State-Of-The-Art Copper Rotating Band

Informations about the material temperature gradients of a rotating band during firing were obtained by metallographic analyses of fired rotating bands. The test projectiles were fired from a M109 with the Swiss Charge 10 and then recovered from a sand wall and cut into flat samples. From the metallographic analysis of the test samples a temperature distribution in the rotating band was derived as shown in Figure 1. This obtained temperature gradient has a good correspondence with former studies [3].

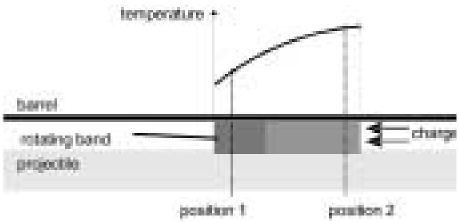

Figure 1. Temperature distribution in a copper rotating band.

2.2 Mechanical Properties Simulation Of A Rotating Band In The Barrel Cone

Another important parameter of the rotating band material properties are the dynamic rotating band forming forces while the projectile is in the barrel cone. These forming forces of a copper rotating band were investigated by analyzing the dynamic material forming velocity and the plastic strain by FEM Analysis (MSC.Superforge).

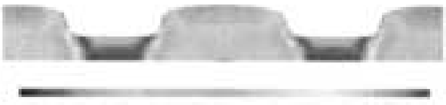

Figure 2: Plastic strain.

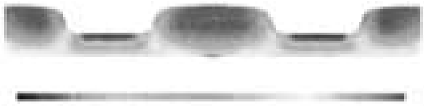

Figure 3: Material forming velocity.

As evident from Figure 2 and Figure 3, the results of the simulation show that the new rotating band material should have a high material ductility together with a high dynamic strength. Considering these requirements, nickel, titanium and Carbon Fiber Composites (CFC) were taken into consideration as possible materials. In Figure 4 one can see the surface pressure and the tensile strength of state-of-the-art rotating bands in comparison with the three new tested materials.

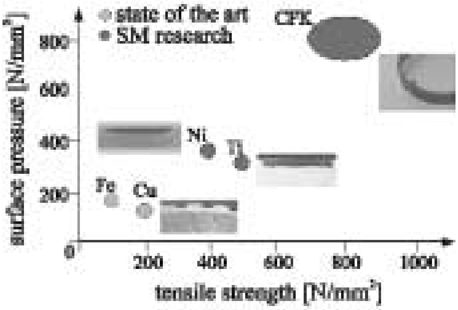

Figure 4: Property area of rotating band materials.

3. EXPERIMENTAL

3.1 Preparation Of The Rotating Bands

The nickel rotating band was fixed to the projectile by a welding process on a welding machine using a wire of nickel grade 2. To increase the evenness of the nickel-steel interface, welding voltage was increased from 27 to 33 V; wire feeding speed was varied from 7.5 to 9 a.u. and the welding speed was changed between 1 to 1.4 a.u.. To extract the heat of fusion, a cooling device was developed which permitted specific cooling-down rates. The subsequent heat treatment process was carried out in a furnace (Nabermultitherm N 11-HR), using an argon inert gas atmosphere. To determine the change in the microstructure, the time frame of 1 to 3 hours was investigated for the recrystallization process, while for the hardening process a time frame of 3 to 6 hours was tested. After this, the rotating band was finished on a CNC turning machine.

For the titanium rotating band the material titanium grade 2 was used. Because of the tendency of forming intermetallic phases it was impossible to find a welding process suitable for connecting the titanium with steel. Therefore a static pressing process was selected. Due to the difference in the crystal structure between copper (cubic face centered with 24 glide planes) and hexagonal titanium (6 glide planes), however, it was necessary to determine a new pressing process for the titanium rotating band. The material was brought into ring shape on a turning machine and then statically pressed onto the projectile by means of a radial press. After this, the rotating band was externally desurfaced on a CNC turning machine.

For the CFC rotating band, a prepreg (Krempel company) cured by means of a standard autoclave process was used. As the structure geometry of rotating bands was difficult to process with CFC a new production process was developed by optimizing the inner structure of the fibrous layers. For the last step of the production process we used a forming device made from a sawn-off groove-field profile of a gun barrel into which the CFC blank was pressed. In the subsequent shrinkage process the projectile was cooled down with liquid nitrogen and then the CFC ring was slid onto it.

3.2 Ballistic Experiments

The ballistic tests were carried out in a firing channel using a M109 weapon under the following environmental influences: temperature 10.9 °C, pressure 950 mbar, humidity 88 %, atmospheric density: 1159 g/m^3. A piezo-type measured-value transducer of AVL was used for the interior-ballistic measurement, installed on the action side of the charge chamber. Standard photoelectric cells of the AVL company were used for the external-ballistic measurement. Charge and projectile were moderated to 15°C prior to firing. The firing channel was vented for one hour after each shot. Firing tests with the charges 5, 7, 9 and 10 were carried out for nickel, and with the charges 5 and 7 for titanium. Tests with rotating bands of the diameters 157.5 mm and 158 mm were made on account of the changed forming behavior in the case of titanium. Firing tests with the charges 5 were carried out with CFC rotating bands.

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The assessment of the ballistic function was made with the aid of muzzle photos of the projectile. For this purpose a digital short-period camera of type Ballistik Range SVR II, set up 7 m after the barrel muzzle, was used. To permit viewing of the entire circumference of the rotating band on the muzzle photo, two mirrors, each with 45° inclination to the photo plane, were used. The following interior-ballistic standard parameters were measured for the course of the gas pressure as a further assessment criterion: Maximum gas pressure P_{max}, Muzzle gas pressure P_{muzzle}, and the interior-ballistic parameters t2, t3 and t4. Additionally external velocities were measured to verify the interior parameters.

4. RESULTS AND DISCUSSION

4.1 Nickel Rotating Band

To be able to fix the nickel rotating band also on a thin-wall cargo projectile it was necessary to develop a new welding process with optimized regularity of the nickel-steel interface to realize a constant wall thickness under the nickel welding on a thin-wall cargo projectile. This work was done on a maraging steel thin-wall cargo projectile.

By optimizing the welding parameters and the heat extraction in the cooling device it was possible to achieve a marked increase of the regularity of the nickel-steel interface. The picture below illustrates the improvement of the characteristic value of regularity Rz.

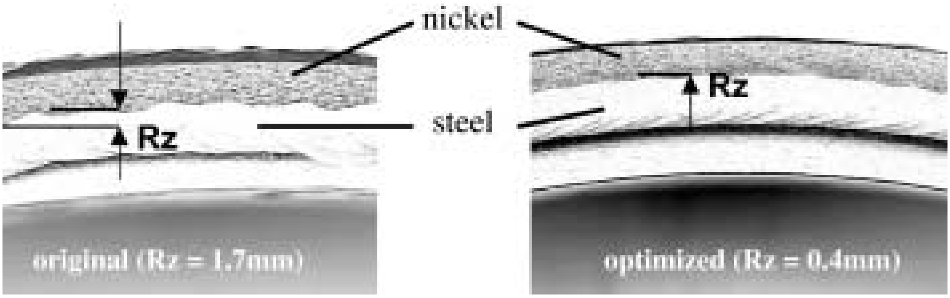

Figure 5: Improvement of the nickel-metal interface regularity (Rz).

As shown in Figure 5, Rz was reduced from 1.7 mm to 0.4 mm thus obtaining a better interface between nickel and steel.

After welding the nickel onto maraging steel the projectile was subjected to a standard heat treatment. After the heat treatment micro-bubbles were detected in the basic steel material in the course of the material aging heat treatment process. Investigations showed that the formation of the micro-bubbles depends on the cooling-down gradient during the welding process. Therefore a heat treatment process was developed to modify the material structure in such a manner that no further micro-bubbles were generated in the subsequent hardening process. The following picture illustrates the effect of the material structure conversion process on the hardening, preventing the formation of micro-bubbles.

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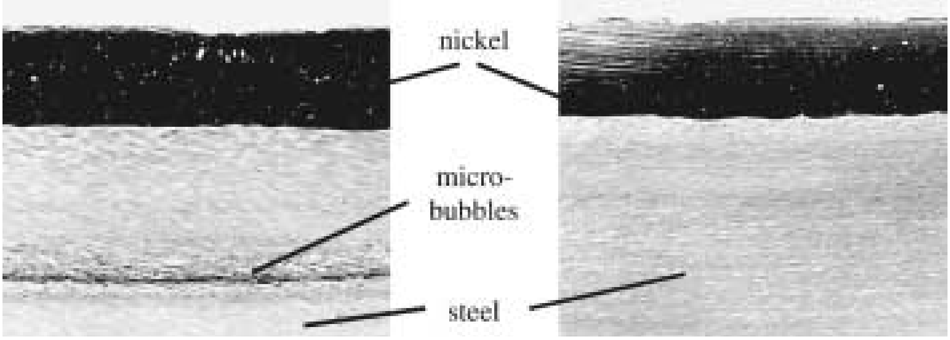

Figure 6: Influences of the microstructure conversion process (left before, right after).

Suitability of the nickel rotating band was investigated by ballistic function tests. The interior ballistic evaluation revealed for each charge, within limits of ± 5 %, the same course of gas pressure as the reference projectile equipped with a copper rotating band. The muzzle photograph (fig. 7) of the test projectile fired with charge 10 shows a marked improvement in the sense that structural edge melting as described for copper rotating bands is no longer observed.

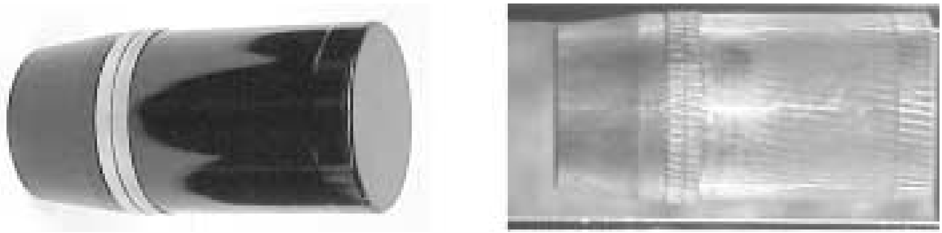

Figure 7: Projectile before (left) and after rotating band forming (right).

4.2 Titanium Rotating Band

During the development of the new pressing process the test showed that only from 600 bar upwards the complete groove of the projectile is filled by the titanium rotating band (see Figure 8).

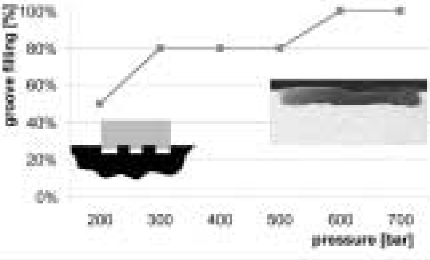

Figure 8: influence of pressure on groove filling.

Ballistic function tests were performed to investigate the suitability of the titanium rotating band. Considering the different forming behavior of titanium, the principle trials were carried out with rotating bands of the diameters 157.5 mm and 158 mm. Both charges showed at diameter 157.5 mm that the maximum gas pressure was reduced on average by 4%, while having the same muzzle gas pressure and no gas leakage. The muzzle photo shows a normal, adequately formed rotating band without mechanical defects (fig. 9). With diameter 158 mm and charges 5 and 7, the interior ballistic evaluation resulted, within limits of ± 5 %, in the same course of gas pressure as the reference projectile with copper rotating band. While with charge 5 the muzzle photograph shows a normal, adequately formed rotating band, with charge 7, small fragments (1–2 mm) detached from the rotating band thus indicating the maximum functional diameter.

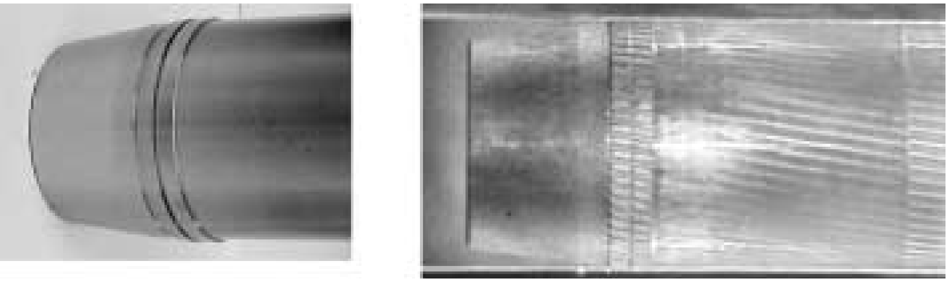

Figure 9: Projectile before (left) and after rotating band forming (right).

4.3 Carbon fiber-reinforced composite rotating band

Because of the low ductility of the CFC compared to copper, the barrels groove-field profile can not be formed on the rotating band during firing. Therefore the weapon barrel's groove-field profile was applied to the CFC rotating band already during the production. For correct positioning of the rotating band's groove-field profile in relation to the groove-field profile of the barrel during loading, a centering lug was provided on the rotating band, engaging in a groove of the weapon's barrel on loading (Figure 10).

For the production of the CFC rotating band specially adapted fibrous tissues were necessary to achieve a defined fiber orientation in relation to the dynamic load conditions inside the rotating band. Step by step the arrangement of the fibrous tissues was optimized to obtain a circular structure with high elasticity, where the preprofiling of the groove-field profile was formed into the outer surface as shown in Figure 10.

Figure 10: Part of rotating band with centering lug.

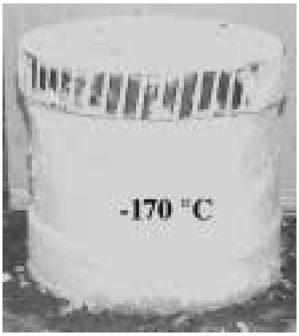

Figure 11: Shrinking of the rotating band on a sample.

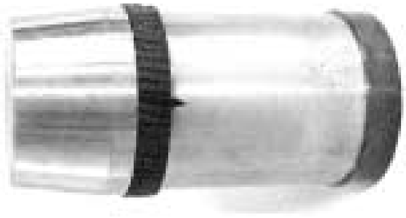

Figure 10: part of rotating band with centering lug.

As welding or pressing of the CFC rotating band onto the projectile was impossible, a thermal shrinking process was developed. The CFC ring was fitted on the projectile by cooling down the projectile jacket to –170°C before the CFC ring was slid in place as shown in Figure 11. After warming of the projectile to room temperature, a positive and frictional connection between the rotating ring and the projectile was obtained as shown in Figure 12.

Short-time dynamic behavior of the CFC rotating band was determined by firing tests. The interior ballistic evaluation revealed a reduction of the maximum gas pressure by 18% in comparison with the copper rotating band. Apart from this, an increase of the muzzle gas pressure by 300% was recorded in comparison with copper. Due to the prestructuring of the CFC rotating band the forming force in the transition cone is substantially reduced, resulting in a premature ejection of the projectile already at low gas pressure.

5. SUMMARY AND CONCLUSION

While all three materials worked as rotating bands, one has to look at their performance individually.

In comparison with the copper rotating band, a marked functional improvement was obtained with the nickel rotating band. In comparison with copper rotating bands the produced utility models displayed a markedly improved structure also in the case of highest charges. The developed production process for nickel rotating bands will also solve other rotating band problems on thin-walled carrier projectiles where numerous problems have been observed so far.

Concerning the titanium rotating band, the suitability was proven. The firing tests also showed that for future rotating bands of titanium the external diameter should be between 157.5 mm and 158 mm.

The suitability in principle was also proven for the CFC rotating band. However to avoid the premature ejection of the CFC-projectile an additional copper ring should be placed behind the rotating band. This copper ring would be deformed during the firing and increase the forming force in the transition cone while the ledge force would still be transmitted by the CFC rotating band.

6. REFERENCES

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