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CERAMBALL

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Author	Checked by	Released by	Approved by
L.Hric	E.Neubauer	E.Neubauer	
Signature	Signature	Signature	Signature

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"CERAMBALL" is a joint funded project by the member states of Austria, Germany, Netherlands, Italy, Sweden, Norway, France and Czech Republic under the umbrella of EDA

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Change List

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20/12/2016			Initial Version
18/05/2018	all	E.Neubauer	Modified version after comments of PAMG
31/05/2018		E.Neubauer	Modifications based on PAMG comments

Content

1 Project Goals

The main goals of the CERAMBALL project can be summarized as follows:

- to identify new ceramic materials which allow a reduction of the weight for personal protection equipment.
- to assess new methods for manufacturing of ceramics inserts
- to identify and investigate the multi-hit performance of developed materials in comparison to the state of the art materials

2 Overview of the Consortium

CERMABALL is a category B project of the European Defence Agency Project. The project started on January, 15th 2015 and finished on April, 30th 2018. In total 11 partners from 8 countries (Sweden, Norway, Netherlands, Germany, France, Italy, Czech Republic and Austria) were participating in the project. Lead nation of the EDA project was Austria. RHP-Technology GmbH, an Austrian SME, was responsible for the coordination of the project. The project partners have a different background and by combining their know-how from the area of material science and processing, design and simulation as well as testing and characterisation it was possible to make a significant progress in the development of ceramic materials for ballistic protection.

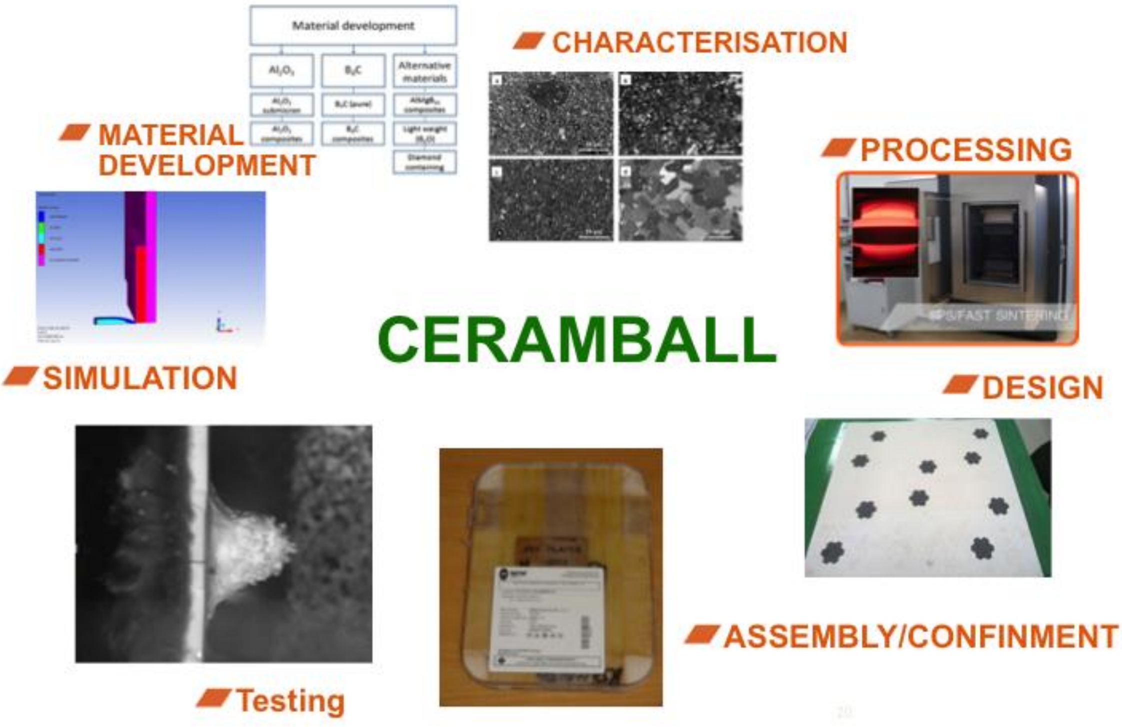


Figure 1: Interdisciplinary character of CERAMBALL

3 Work performed

The project was structured into 5 technical workpackages, which are shown in Figure 2:

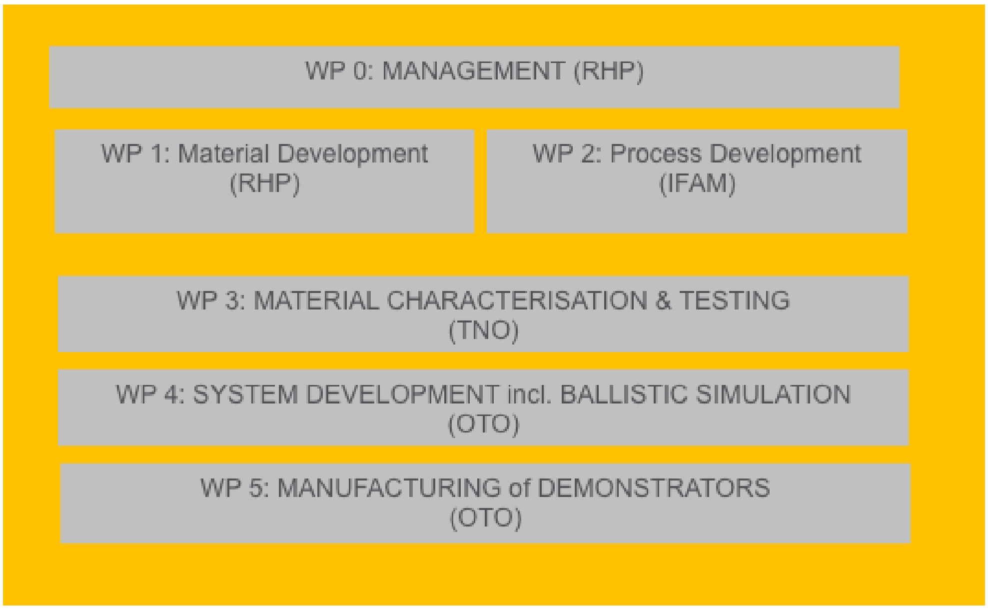


Figure 2: Overview of the workpackage structure of CERAMBALL with information on the lead of the workpackage

The main activities are summarized as follows:

WP 1: Material Development
Within this workpackage in total more than 10 material families have been investigated. These materials have been grouped into B4C and Al2O3 based ceramics. The B4C based composites represent the group of high performance low density ballistic materials currently available on market. The Al2O3 based composite materials have been developed as an alternative to standard Al2O3 ceramics. An additional group of materials, so-called “alternative materials”, were investigated. Amongst them lightweight and super hard phase containing materials (e.g. diamonds) as well as boron rich materials were developed. The materials were simultaneously studied and developed by three different partners RHP, IFAM and ISL. Each of them used their specific techniques of powder pre-treatment and consolidation.

WP 2: Process Development
The process development was an activity, which was running in parallel to the material development (WP 1). The focus was on the use of Spark Plasma Sintering (SPS) technology or Rapid Hot Pressing (RHP) for the manufacturing of ceramic inserts with zero porosity. Both methods are characterised by a very high heating rate and a reduced overall cycle time. Starting from small sized ceramic samples (20 mm) the technologies were successively upscaled finally to a tile size of 300 mm x 250 mm. A systematic process analysis was made including the use of simulation for the optimised layout of graphite pressing dies.

WP 3: Material Testing and characterisation

Materials developed in WP 1 were investigated with respect to density, hardness and mechanical properties. Additionally they were analysed with respect to the microstructural characteristics.

Larger ceramic tiles were tested with respect to the ballistic performance allowing the ranking of the most promising ceramic materials. Besides using the standard depth of penetration measurement, a new method for the characterisation of the ballistic performance was developed, which was based on a Residual Energy Method (REM).

WP 4: System Development and Ballistic simulation

Within this workpackage a focus was on the development and application of simulation tools in order to predict the ceramics performance in a ballistic test. Starting from screening of different simulation models available from literature, the most promising were selected and adapted in order to predict the ballistic performance of the ceramics. One of the challenges identified was the lack of data for ceramics when loaded at high strain rates.

WP 5: Manufacturing of demonstrators

In order to assess the performance of the developed ceramic materials, the ceramic tiles have been integrated and assembled into a ballistic test system. By using the same procedure commercial ceramics have been assembled as well and finally tested using the same conditions in order to allow a direct comparison. Two different types of demonstrators were manufactured. One demonstrator was consisting of small individual hexagons, which were assembled to a large panel and the second demonstrator was made from a large ceramic plate with a size of 300 mm x 250 mm which was integrated in a soft armor system. Several demonstrators from each type were prepared and were tested using a V50 testing method/ballistic limit testing and compared to commercial available ceramic grades.

Based on these results conclusions were drawn and a first cost estimation for the processing of ceramics by using advanced manufacturing methods were derived.

4 Results & Highlights

Within the CERAMBALL project several „building blocks“ which are relevant for a ballistic protection system were developed and combined. The highlights can be summarized as follows:

4.1 Highlights in Materials Testing

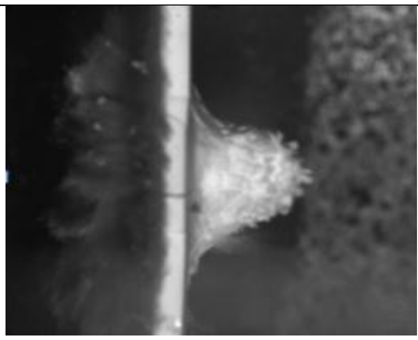
- **Round Robin Test using „Depth of Penetration“(DoP)**

5 partners were participating in this round robin test of European laboratories for evaluation of ceramic materials. A large scattering of the results was observed when testing was performed at different laboratories.

Based on these results, which demonstrated that DoP test is not suitable for ranking and assessment of ceramic materials, an energy testing method was elaborated.

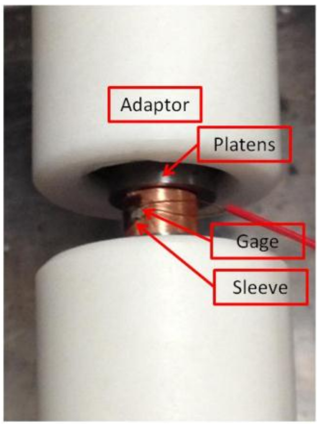
- **Development of “Residual Energy Method” for ballistic testing**

In the area of ballistic testing one of the highlights was the development of a testing method which allows to perform a ranking of ceramic materials with respect to their ballistic performance in an efficient way. This method is based on the measurement of the residual energy when a ceramic tile is hit by a projectile. The residual velocity/energy of the projectile is measured which allows to do a ranking of the ceramics with respect to the ballistic performance.



- **Development of mechanical dynamic testing**

A Mechanical dynamic testing method was developed for characterization of ceramics in order to understand the processes occurring during the interaction between the ceramic materials and projectile. An experimental set up has been developed in order to characterize the dynamic behavior of the fragmented ceramic. The experiments were also useful to improve the understanding of relationship between the microstructure and the mechanical behavior of these materials. It was possible to test ceramics confined in a metal at strain rates up to 10^4 s^{-1}. These data are especially of relevance for the input in simulation.



4.2 Highlights in Materials & Development for weight reduction

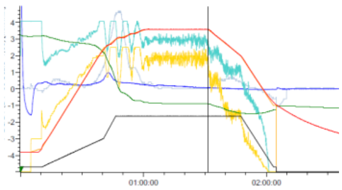
- **Development of new ceramic grades**

Within the project a large set of new ceramic grades have been developed and investigated. Amongst the materials there were several Al2O3 based and B4C based composites which have been prepared by in-situ reaction processes. These new ceramic grades offered on a sample level improved ballistic performance when compared to commercial available ceramics. Additionally material grades have been developed which offer an approx. 200-300°C lower processing temperature compared to standard B4C materials.

- **Demonstration of high speed manufacturing of ceramics at reduced costs**

By using Rapid Hot Pressing technique it was possible to demonstrate the manufacturing of ceramic plates with a reduced process cycle time. A factor of 3 could be demonstrated when compared to the conventional hot pressing process.

Taking advantage of the fast processing in combination with an up to 300°C lower processing temperature for the developed B4C composite compared to commercial available materials, an economic advantage in the processing could be demonstrated. Based on first calculations for a large volume production a cost efficient manufacturing can be achieved when compared to high performance ceramic inserts. An issue with respect to costs are the raw materials which need to be further reduced.



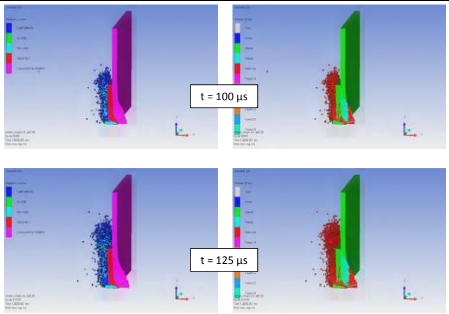
- **Development of large size Rapid Hot Pressing for Manufacturing of Ceramics**

Rapid hot pressing could be applied as a suitable technique for the manufacturing of large ceramic plates. Starting from first samples with diameter 50 mm, within the project finally plates from B4C based composite materials could be prepared by Rapid Hot Pressing. Cycle times for processing could be reduced significantly compared to conventional hot pressing. This allows manufacturing ceramics plates in a cost efficient way.

4.3 Highlights in Development of Ballistic Systems

- **Computational simulations**

To support the design of ballistic systems simulations were performed using ANSYS AUTODYN. The simulation activity studied the basic interactions in ceramic materials as well as specific demonstrator materials. The simulations were set up to reproduce the Energy Method configuration. Simulated results have reached best agreement with the experimental results for the Al2O3 ceramic where only a deviation of 5% was observed.



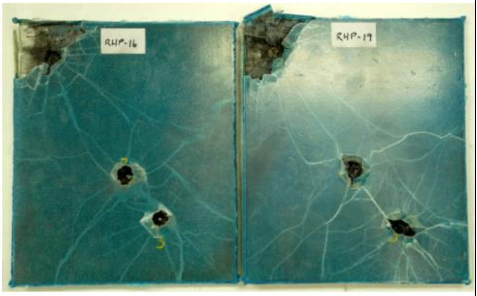
- **Development of Confinement Methods**

Confinement is one of the ways in order to improve the performance of the ceramic. As part of the CERAMBALL activities various ways to pre-tension the ceramic tiles have been assessed. In an intensive testing campaign numerous ceramic plates have been tested regarding the ballistic limit (V50). It could be demonstrated that by the pre-stressing of the ceramic tile an improvement of more than 7 % could be obtained, which means this would enable to either reduce the weight of the ballistic system when compared to state of the art solution or which would result in a higher protection level.

- **Assembly of Demonstrator and Testing**

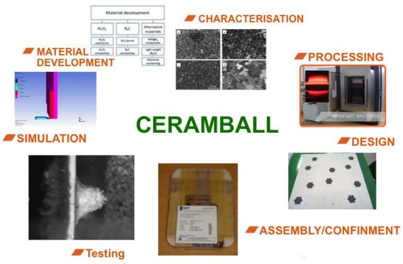
From the two selected ceramic materials several sets of ballistic demonstrators have been prepared and tested. The first 20 plates of the CERAMBALL developed B4C composite material showed an equal performance to a commercial available B4C reference materials. This indicates, that with additional improvement and optimisation as well as applying confinement methods further improvements are possible.

The developed Al2O3 composite material was compared to a state of the art Al2O3 reference. Although due some issues with the densification when manufacturing the hexagons, it was possible to obtain a similar performance compared to the reference material.



- **Final Assessment**

Within the CERAMBALL project several „building blocks“ relevant for a ballistic protection system could be successfully developed. The next steps is the combination of these „building blocks“ inlcuding the optimisation of individual steps. The cooperation and support by the European Defence Agency enabled the cooperation and partnership of 8 nations.



5 Outlook

Follow up activities will concentrate - besides the improvement of materials and processes - on the development and improvement of testing methods to increase the reliability and accuracy of the testing methods especially for a complete ballistic protection system. Within the CERAMBALL project it could be shown that the Residual Energy Method is suitable for the ranking of ceramics. Today the assessment and the approval of a ballistic protection system which contains a ceramic insert is still very time consuming and requires a lot of effort and many ceramic tiles. One goal of future activities is to improve the testing methodologies to allow a cost reduction in the development and assessment of ballistic protection systems. In addition to that the improvements from the project using confinement techniques as well as results from simulations will be integrated and demonstrated on a system level.

6 Deliverables

The following list shows the deliverables which have been prepared during the project.

Deliverable	Content	Date
D 0.0.1	Annual Report and Cost Statement	T0+12
D 0.0.2	Annual Report and Cost Statement	T0+24
D 0.0.3	Annual Report and Cost Statement	T0+39
D 1.1.1	Report Literature Review/Update	T0+4
D 1.2.1	Report on Material Research Programme	T0+4
D 1.2.2	Material Requirement Definition for ballistic materials	T0+4
D 1.3.1	Progress Report on Development of Composite Materials	T0+12
D 1.3.2	Progress Report on Development of Composite Materials	T0+24
D 1.3.3	Final Report on Development of Composite Materials	T0+30
D 1.4.1	Progress Report on Material Development of B4C materials	T0+12
D 1.4.2	Final Report on Material Development of B4C materials	T0+18
D 2.1.1	Report on Literature/Patent update for manufacturing	T0+3
D 2.2.1	Report and Plan on Process development	T0+3
D 2.3.1	Progress Report on Process development	T0+12
D 2.3.2	Progress Report on Process development	T0+24
D 2.4.1	Progress Report on direct hot pressing of ceramics	T0+12
D 2.4.2	Progress Report on direct hot pressing of ceramics	T0+24
D 2.5.1	Progress Report on Confinement	T0+12
D 2.5.2	Progress Report on Confinement	T0+24
D 2.5.3	*Progress* Report on Confinement	T0+30
D 2.5.4	Final Report on Confinement	T0+39
D 3.1.1	Report on ballistic test standards	T0+8
D 3.2.1	Report on ballistic test methods	T0+8
D 3.3.1	Progress Report on Microstructural Analysis of developed and reference materials	T0+16
D 3.3.2	Final Report on Microstructural Analysis of developed and reference materials	T0+28
D 3.4.1	Progress Report on Dynamic/Mechanical Testing results	T0+16
D 3.4.2	Final Report on Dynamic/Mechanical Testing results	T0+28
D 3.5.1	Progress Report on ballistic tests on component level including post impact analysis	T0+16
D 3.5.2	Progress report on in-situ analysis during ballistic testing	T0+16
D 3.5.3	Final Report on ballistic tests on component level including post impact analysis	T0+28
D 3.5.4	Final report on in-situ analysis during ballistic testing	T0+28
D 3.6.1	Report on Material Selection for Demonstrators	T0+24
D 3.6.2	Final Report on Material Selection	T0+39

Deliverable	Content	Date
D 4.1.1	Design Report for set-up of demonstrator plates and ballistic insert	T0+16
D 4.2.1	Progress report on simulation including “demonstrator plates” and “ballistic insert”	T0+16
D 4.2.2	Progress report on simulation including “demonstrator plates” and “ballistic insert”	T0+28
D 4.2.3	Final report on simulation including “demonstrator plates” and “ballistic insert”	T0+39
D 5.1.1	Design report for “demonstrator plates” and the “ballistic insert”	T0+26
D 5.2.1	Ceramic plates /”demonstrator level”	T0+30
D 5.2.2	Procurement of commercial ceramic plates “demonstrator level”	T0+30
D 5.3.1	Testing and Analysis report of demonstrator evaluation	T0+39
D 5.4.1	Assembly of ballistic insert and testing	T0+39
D 5.5.1	Final Assessment & Conclusions	T0+39
D 5.5.2	Publishable Synthesis Report	T0+39