Mid-term evaluation

Title of the programme: **MAteRials in TechnologIes for New Applications**

Acronym of the programme: **MARTINA**

S4 priority area: **Development of materials as end products**

Evaluator:

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1. Introduction: basic data on the project and mid-term evaluation

The evaluator for the mid-term progress report was also reviewer of the original proposal MARTINA. The evaluation included a seminar presentation from the coordinators of the various RDPs, taking place in Ljubljana on 7 March 2019, and a visit to two companies involved in the project MARTINA: SIJ Metal Ravne, working on the production of advanced steel, and Impol, working in the production of advanced Aluminum alloys.

MARTINA started in August 2016. The total value of the program is 9.6 M€ with 3.6 M€ coming from private sources. 16 partner organizations take part in the project, about half of which are university laboratories or research centers and the rest companies operating in the field. In addition to the good balance companies/academia, there is also a fair balance between the East and the West regions of Slovenia.
The project is coordinated by the INŠTITUT ZA KOVINSKE MATERIALE IN TEHNOLOGIJE (IMT) in Ljubljana, director Prof Matjaž Godec.

The primary objective of the program MARTINA is to strengthen the position and the role of Slovenian industry in the field of materials, particularly in the field of special steels, aluminum and metal containing composites, new advanced multifunctional materials, with particular reference to the needs of the automotive industry. This should result in increasing the competitiveness of Slovenian industry in the global market. The project identifies technological advances as the key factor for such strengthening. An effective collaboration between companies and academic research centers and universities is seen as the way towards technological advances.

The MARTINA project correctly looks for a coupling between the development of new advanced materials and new technologies for the production of engineering components like additive manufacturing and novel forming procedures. In turn, such new technologies often set new requirements for tools and consequently new requirements on materials. MARTINA hence tries to have a global approach to innovating the use of materials in industry by focusing on the 3 inter-related aspects of 1) Materials, 2) Tools, 3) Technologies.
Therefore, 3 levels of prototyping have been considered in the project:

- Prototypes of new materials: development of prototype tool steel for hot working, prototype of tool steel for working with plastic, prototype of high-strength steel (HSS), prototype of new aluminum alloys with improved mechanical properties and increased use of recycling, prototype of multicomponent permanent-magnet materials. The development of tool steels is a common need for all sub-areas (e.g. study of new steels for treatment of plastics and Al).

- Prototypes of new tools: development of tool prototype for hot working, tool prototype for working with plastic, development of an injection tool prototype designed by additive manufacturing (3D metal printing)
- Prototypes of finished (semi)products for use in the automotive and electrical industries, prototype of a shaft seat, prototype of an ESP holder, prototype of a magnetic ring, and prototype of a demanding 3D-printed part for the automotive industry.

Let's notice that, although the project is mainly focused to automotive industry, nevertheless several different applications in other industrial fields have arisen in the framework of MARTINA, as it will be described later.

MARTINA also puts particular emphasis on the ecological impact of the production and the use of these new materials. In order to allow for a significant ecological "saving", the new materials should:

- allow for recycling, i.e. scrap material can be used for their production
- allow for easier production process, e.g. reduce the needs for multiple phases or multiple thermal treatments
- possess characteristics allowing to minimize ecological impact. For instance, reduction of weight of tools and components can allow reducing fuel consumption in cars, thereby implying significant less pollution.

`The project is articulated in 6 RDPs, listed below with the respective RDP leaders:

- RDP1: Development of the new tool steels with better thermal conductivity for realizing new high-strength low-weight tools, led by SIJ Metal Ravne;
- RDP2: Development of new ("3rd generation") high-strength steels again with weight reduction and reduced environment impact, led by Store Steel;
- RDP3: Development of new high-strength aluminum alloys with increased use of recycling, led by Impol;
- RDP4: Two main sub-programs:
  - Development of new multicomponent materials for advanced composites, led by TECOS,
  - Development of material with improved permanent-magnet properties, led by Kolektor;
- RDP5: Development of injection moulding tools based on hybrid 3D printing technology, led by RCJ;
- RDP6: Development of components from new materials for the automotive industry, led by TPV.

The articulation in RDPs will be used in the following to describe the main achievements of the project.

2. Assessment of the progress made with regard to the objectives outlined in the project proposal of the programme and its research and development projects:

The analysis of the progress made with regard to the objectives outlined in the project proposal will be done for each RDP separately. Finally, some comments on the interaction among the various RDPs will be given.

RPD1: Hot work tool steel

This RDP is centered on development of steels optimized for work at high temperature. It is coordinated by SIJ Metal Ravne while form the academic side the Institute for Metallic Materials and Technologies (IMT) is in charge of laboratory, vacuum heat treatment, testing of fracture toughness.

In working conditions, tools realized with steels may be exposed to high-temperature cycles with rapid heating and cooling. They are also subject to high mechanical loads and to abrasive/adhesive wear (e.g. for plastic moulding). Therefore, "hot work" steels must have high thermal fatigue resistance, high temperature stability, wear resistance. The key parameter here is thermal conductivity at the tool operating temperature (thermal conductivity is also directly related to the thermal fatigue resistance). This can be improved by optimizing the alloy, the microstructure, the micro-homogeneity, while at the same time high impact toughness and hardness should be maintained. The development of new hot work tool steel should result in longer tool life and shorter production cycles/higher productivity therefore meeting market demands.
This RDP aims in particular at:

- Developing a new hot-work tool steel with higher thermal conductivity for high-pressure die casting of aluminum and Al alloys, hot stamping, extrusion of aluminum and die forging.
- Development of a new corrosion resistant tool steel for plastic moulding with better polishability and machinability.

15 prototype laboratory steels were prepared, out of which 2 of them satisfied the required criteria for thermal conductivity, hardness, impact toughness, etc. In particular the criteria for thermal conductivity, initially set to 45 W/mK (following NADCA # 229-2016 recommendations) was increased to the more stringent value of 50 W/mK. One of these two steels (the SITHERM S140R) was used for the fabrication of larger laboratory batches, and analyzed in detail by making 6 bigger laboratory heats of 500 kg in an open air induction furnace, one laboratory heat of 2000 kg in a vacuum induction furnace, and one prototype heat of 2000 kg in a vacuum induction furnace.
When compared to the best hot work tool steels, the advantage of SITHERM S140R are:

- It can be produced from commercially available scrap (while usually steels with such characteristics require ultra-high purity raw materials such as electrolytic flakes).
- It has higher hardness (allowing production of larger tools).
- Thermal conductivity is high at work temperature (while usually it is the highest at room temperature)
- It requires less demanding heat treatment.

The higher thermal conductivity and hardness will allow for the production of longer-life tools. This, the less demanding heat treatment, and the possibility of using commercially available scrap for the production imply a significantly reduced ecological impact.
The development of the new steel S140R by SIJ Metal Ravne is considered as one of the key-success points of MARTINA.

RDP2: High Strength Steel (HSS)
The main focus of RD2, coordinated by the company Store Steel, is the development of high-strength steels and the optimization of their manufacture process. The aim is to increase the mechanical properties of the steels used for safety parts in the automotive industry, thus reducing the final weight of components and consequently the fuel consumption (ecological impact).
Several working packages did run in parallel to:

- Determinate possible applications (market oriented) and consequently identify the needed characteristics of the new material
- Study the influence of alloying elements on the microstructure and properties of new high-strength steel (including the simulation of thermo-mechanical treatments)
- Optimize the manufacturing processes and technology (chemical composition of the steel, control of non-metallic inclusions, optimization of the manufacturing process and of thermo-mechanical and heat treatment)

- Characterize the mechanical and corrosion properties the final high-strength steel batch.

The main results of RDP2 have been:

- The development of new (“3^{rd} generation”) high strength steels for applications in car industry, with improved strength and better fatigue resistance within the parts affected by heat. The new steels included two high strength steels for forged bearing parts. The first one provides 20% higher strength and 5 times better fatigue resistance, obtained through optimized Si-Mn-Cr composition, production process and heat treatment. The other one is a Si-Cr-Ni type steel where high strength and 2 times better fatigue resistance can be obtained without the need for additional heat treatment but the high Ni content (> 3%) makes it expensive.
- The development of new HSS for the automotive industry with application to safety elements. This is characterized by large values of elongation, 30% weight reduction, 10 % lower material and production costs, higher reliability, material price < 800€/t.

It is important to notice that these steels have been used for the realization of prototypes within RDP6. In particular:

- The 3rd generation HSS has been used to realize prototypes of conrods.
- The HSS for safety elements has been used to realize prototypes of structural elements like a seat connecting bar.

This step of prototyping proves the real interconnection between various RDPs (here RDP2 and RDP6) and the real commitment of the project MARTINA not only to realize new interesting materials, but also to find appropriate applications for these materials which meet the demand of (automotive) industry or even anticipate such needs.

RDP3: Aluminum alloys

This RDP, led by Impol, is dedicated to research on new improved aluminum alloys for industry with better mechanical properties. Coherently, this also implies the development of new manufacturing technologies. The key objectives of project are:

- aluminum alloys with high mechanical properties
- research of interactions of aluminum alloys with tool materials in casting and working
- research of new casting technologies
- research of alloys and rolling technologies to improve the deep-drawing properties of sheet.

The work done within this RDP is very vast and of very high quality from the scientific point of view, with a really global approach to the study of aluminum alloys, from the academic and theoretical point of view to the production line. The results and outcomes of this RDP are clearly of the same high-quality of the other RDPs dedicated to steels and composite materials. One particular example: the partners of the RDP have compared their results with the techniques and the model developed at the Ecole des Mines de Nancy, France, and after the first tests, they opted for vertical casting of rods instead of horizontal casting.
Also, there has been a significant interplay between RDP1 (realization of hot work tool steel) and RDP3: steels with optimal properties like fracture toughness, thermal conductivity, temperature stability, resistance to heat, and mechanical fatigue have been selected for realizing the tools to work with the new Al alloys.

One key point of the RDP, from the environmental and economic viewpoints, is the possibility of an increased use of secondary materials while simultaneously maintaining or even improving the properties of aluminum alloys for up-to-date technologies.

With this respect, the initial expectation of the project was quite high. On one side these expectations have been met: the visit to Impol confirmed that a large part of aluminum used in the company comes from recycling of secondary material (process and amortization scrap). On the other side however, it was found that the quality of the starting input material has a major influence on formability of advanced Al-alloys. Even if trace elements of up to 0.05% have generally no significant effect on the mechanical properties of the alloy, nevertheless it is practically almost impossible to use "normal recycled" aluminum for production of advanced alloys. Its use is therefore restricted to low-quality general-use Al alloys.
As a part of the project, a high-strength version of aluminum alloy 6082 was developed and later it was categorized as the new alloy 6086 and registered with the American Aluminum Association, which is a huge recognition for the research carried out within MARTINA.

RDP4: Polymer materials and composites
RDP4 is also a very vast project with many participants and several objectives and tasks. There are however two main lines:

- Research, development, characterization, processing optimization, up-scaling and technical validation of multi-component polymer materials including new materials and new technologies for nanocomposites and hybrid multicomponent materials (WP1) and their assembly (WP2). Materials include in particular the use of carbon nanotubes (CNT), nanocrystalline cellulose (CNC), graphene oxide (chemically modified and unmodified GO), nano zinc oxides (nZnO), etc. It also includes the study of up-scaled production of gold nanoparticles using Ultrasonic Spray Pyrolysis. Concerning assembly, the development of joining techniques is critical both on metal substrates and for joint metal-plastic parts. Approaches include plasma treatment, mechanical treatment, chemical silanization, etc.
- Development of multicomponent magnetic material based on anisotropic magnetic particles (magnetic powder) embedded in a binder matrix. New technological process for their shaping in a magnetic field during the injection moulding process have been studied, allowing for 40% higher magnetic field efficiency in the final product.

As for other RDPs, there has also been a significant interplay between RDP4 and RDP6 with the realization of prototype products from multi-component materials applied to the automotive industry (e.g. hybrid construction carrier for ESP system) but, and it is very interesting, with possible applications to very different fields, including medicine. For instance, PMMA with gold nanoparticles shows antibacterial properties (thanks to the presence of gold NP). This can result in dental nanocomposites (developed prototype) or can find application in packing industry. Concerning multicomponent magnetic materials, prototypes of magnetic rings have been jointly realized by KOLEKTOR and the institute IMT.

RDP5: technologies for production of industrial parts
This RDP, led by RCJ (Razvojni Center Jesenice), is centered about development of additive manufacturing technologies, combining SLM (Selective Laser Melting) and WAAM (Wire Arc Additive Manufacturing) with the more specific goal of developing complex components for injection moulding in industry (e.g. mould inserts with conformal cooling channels).

Normally, it is difficult to use steel with additive manufacturing. In this framework, the project initially oriented towards developing a new steel powder (from stainless steel SINOXX 4725). However, in the end, this showed a low compatibility with the printing machine. Therefore, the research shifted towards the use of maraging steel (no carbon). By optimizing the heat treatment of the maraging steel, it was possible to optimize applicative properties like toughness, strength and desired microstructure.

Another important point was the development of hybrid techniques combining SLM and WAAM technologies (SLM can only be used for single materials, while generally WAAM offers worse spatial resolution).
Finally, mould inserts were realized with conformal cooling systems, leading to 30 % shorter moulding cycle, in comparison to conventional cooling systems, and more uniform heat dissipation.

The work has been done in collaboration with MARSi - Mario Šinko s.p. (Plastic solution - 3D metal print) which is proprietary of the system for additive manufacturing. MARSi took part in MARTINA as a sub-contractor for RDP5.

The work done in RDP5 has shown the advantages but also the problems related to additive manufacturing.
In particular, additive manufacturing allows for high precision in realized items and for fast access to the market (you do not need to build a specific production plant to allow production of your items). But on the other side it does not seem really adapted to mass production. Hence, 3D printing is good for production of prototypes, production of items in small quantities, or for very specific (niche) applications like space industry. On the other side, it might not be adapted for production of large quantities of components for the automotive industry.

RDP6: development of prototypes
RDP6 is the part of the program, which is dealing with the experimental development and includes the preparation and development of prototypes, as well as their analysis and testing in controlled environments. It is led by TPV, an innovative and state-of-the-art development supplier with core operations in the automotive industry.
Main goals of RDP6 are:

- Realizing prototypes of the two new tool steels developed in RDP1 (SITHERM S140R and SITHERM S142)
- Realizing prototypes of the new HSS developed in RDP2
- Realizing prototypes of the new aluminum alloys developed in RDP3
- Realizing prototypes using multicomponent materials (RDP4)
- Realizing prototypes using the new multicomponent magnetic material (RDP4)
- Realizing prototypes of tool steel using 3D printing procedure (RDP5)
- Realizing prototypes of a complex 3D printed item (RDP5)

Several prototypes have already been realized (as described elsewhere in this report) and RDP6 is still running until the end of 2019. Among the realized prototypes one should recall here:

- Dental nanocomposite based on PMMA and gold nanoparticles
- Protective panel on the handholds in TAM buses
- Protective covers on household filters for water purification
- Hybrid carrier for ESP systems
- Magnetic rings
- Tools for injection molding of polymers
- 3D printed insert tool (complex 3D printed item).

2.1. <u>General observations with regard to mid-term report and visit</u>

The evaluator had a very positive impression from the presentations of various mid-term reports from the different RDPs and from the visit to SIJ Metal Ravne, working on the production of advanced steel, and Impol, working in the production of advanced Aluminum alloys.

It seems that this project is running well and it is running within its time schedule and deadlines.
The project is organized in different RDPs which sow a real level of exchange between them. Similarly, the exchanges between academia and industry seem to be deep and productive.

One question which was discussed during mid-term presentations was the creation of new jobs. The original proposal was saying that about 30 new jobs could have been created as a result of MARTINA. In the evaluation, it turned out that assessing the real number of employed persons is a quite difficult task. However, the other related point is that indeed MARTINA offers the possibility to the involved companies to maintain some leading role with respect to international competitors. Therefore, industry innovation through use of advanced technological and scientific research appears as a tool for maintaining a leading position in the market and of preserving existing jobs.

Another benefit from the MARTINA program is to bring industry and academia closer. This implies that universities and research centers can train students by involving them in the project and has therefore a significant pedagogical impact. It also increases the motivation of young people to do research in industry while keeping contacts with academia. In turn, this further contributes to develop research in industry (innovation through research) and in bringing academia closer to industrial needs.

2.2. <u>Key highlights: which achievements stand out in your opinion</u>

The evaluator considers that MARTINA is a highly-successful project. There are many “key highlights” from the different RDPs (these have somewhat already been described before). In particular:

- RDP1: development of new hot work steel with 50% higher thermal conductivity at the relevant work conditions (high temperature). Better thermal conductivity allows for greater resistance to thermal fatigue and shortening production cycles
- RDP2: development of HSS steel which is 20% stronger 5 times better fatigue resistance with simpler and more energy-efficient heat treatment. This is a useful material for forged bearing parts (i.e. conrods)
- RDP3: development of a new Al alloy registered with the American Aluminum Association (alloy 6086)
- RDP4 (a): development of a new multicomponent magnetic compound, requiring lower injection moulding temperatures and allowing more efficient magnetization.
- RDP4 (b): development of a new carrier for the automotive industry, based on a combination of aluminum alloy and plastic instead of steel, which is 30% lighter, thus lowering the weight and the energy consumption of produced cars.
- RDP5: demonstration of the potential of hybrid technologies (SLM-WAAM), allowing design of mould inserts with conformal channels and deposition of high conductivity materials, thus better controlling the cooling and heat exchange.

2.3. <u>Changes: if any changes were made to the project, do you assess them as reasonable and sufficiently well elaborated</u>

No detectable significant change was observed by the evaluator (apart from small adjustments which are normal to research projects)

2.4. <u>Work plan till the end of the project (comment how realistic is its implementation)</u>

The various RDPs have well posed the basis of success for the final phase which is mainly concentrated on the realization of (additional) prototypes within RDP6 and their validation. The evaluator has no doubts that the partners of MARTINA will be able to conclude their project very positively.

3. Role of the partners in the project: evaluator's assessment

MARTINA is a well-balanced project where all the partners seem to have taken an active and positive role. Of course, not all the partners have the same size nor the same involvement in the project, but in general it seems that everyone is contributing "as much as it can" (and as it should). MARTINA is well balanced for what concerns contributions from the East and the West regions of Slovenia and economically: the non-governmental contribution is significant (3.6 M€ over a total of 9.6 M€, i.e. about 37%).
Finally, MARTINA has a balanced participation from Academia and from industry (about 50% - 50%). The evaluator believes that MARTINA is one of the best examples which he has ever seen of real collaboration and synergy between industrial and academic partners, a project really moving from novel academic ideas up to concrete production.
The links among different RDP are also significant. Each RDP is finally linked to RDP6 (realization of prototypes) but there are other, equally significant, links between individual RDPs. For instance, RDP1 (hot work tool steels) is linked to both RDP3 and RDP4 (identifying the best tool steels for treating Al alloys or for treating plastics needed for multicomponent materials).

4. Internal (between the project partners) and external communication: assessment on the basis of evidence provided during the visit (if none, this deserves to be mentioned as well)

There have been several communication activities which the partners together (as consortium) have actively promoted. In particular the consortium had a significant participation in two international conferences:

- 25th ICM&T – International Conference on Materials and Technology, October 16-19, 2017, Portorož, Slovenija
- 26th ICM&T – International Conference on Materials and Technology, October 3-5, 2018, Portorož, Slovenija

5. Assessment of dissemination and exploitation of the project results in the phase TRL7-9 (during the duration of the programme and in the period after the completion of the research activities)

TRL7-9 concerns the final phases of development of real products staring from an initial idea. These include demonstration of the prototype system in an operational environment, qualify the real system through tests and demonstrations, and finally validate the real system through successful operations. Many of the first realizations of RDP6 can be considered to be in this stage (moulding tool with conformal cooling system, Mould inserts made with SLM technology, third generation high-strength steel, conrods made with third generation high-strength steel, Hybrid carrier for ESP system, etc.).
Although the evaluator is not aware of any dissemination and exploitation of project results done until now, some common activities are specifically planned in the future in relation to TRL7-9, which will be organized by the end of the Martina program and also implemented after Martina closure:

- The Martina promotion brochure
- The Martina open promotional program conference, June 6, 2019, Novo mesto
- 27th ICM&T – International Conference on Materials and Technology, October 16-18, 2019, Portorož, Slovenija

6. Assessment of quality of main scientific achievements (scientific excellence in line with planned, any special success stories)

There are many important outcomes from MARTINA. Among them:

- The development of new tool steels (RDP1)
- The development of a new Aluminum alloy (AA6086).

plus many others as specified elsewhere in the text.

However, the point which the evaluator would like to stress here is that all these results have been obtained through a very high-quality scientific work which involved both Academia and Industry. The path to the realization of new materials has clearly followed a high-quality scientific approach based on extensive review of available data in scientific and technical literature, on “design” of new materials using advanced simulation tools, on experimental realization of preliminary batches in the laboratory and extensive experimental tests, to finally proceed, when everything else was positive, to the realization of larger batches for industrial testing.
MARTINA mid-term presentation showed some really good science mixing chemistry, physics, mathematics, and advanced simulation codes.

7. Cooperation between public and private partners (assessment of synergies)

I believe that the cooperation between public and private partners has worked very well within MARTINA. It is really a good example of how this cooperation should work (these aspects have also been described in detail elsewhere in this report).

8. Concluding remarks and recommendations

The general assessment of the MARTINA project shows that this is:

- Well managed. The central coordinating institute (IMT) assures an effective coordination and management of the project. The institutions/ companies coordinating the various RDPs …
- Effective in terms of collaboration. MARTINA is a successful example of real collaboration between research centers and universities and industry and companies.
- Effective in term of results. The consortium has obtained a significant number of important results.

The perspectives for the future are good (completing RDP1 to RDP5 and successfully implementing prototype construction in RDP6).

The consortium partners expressed a high level of satisfaction about the fact that different teams from different areas of material science could work together, especially in terms of knowledge exchange and further cooperation. At the same time, they sincerely expressed the major challenges and difficulties they met during the project:

- The fact that preparation of samples is time consuming (samples manufacturing and preparation is a bottle neck)
- The fact that a lot of experimental laboratory batches is needed for optimization
- The fact that some kinds of tests (e.g. corrosion and fatigue tests) are time consuming
- The fact that theoretical modelling and simulations (using commercial tools) do not cover all possible effects (especially synergistic effects)

- The fact that results from laboratory research or pre-tests are not directly transferable to the industrial scale.

One positive consequence of THE PROJECT is also that two new projects involving several MARTINA partners have been already submitted in 2018, as a result of the successful cooperation in Martina program. These are:
ČMRLJ: Achieving cleanles and properties by microalloying of steels *“Doseganje Čistosti in lastnosti z MikRo Legiranjem Jekel”*
MARTIN: Modeling of thermo-chemical processing of aluminum alloys for top products *“Modeliranje termomehAnskega pRocesiranja aluminijevih zliTIn za vrhuNske izdelke”*