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A generic transformation of advanced materials technologies: Towards more integrated multi-materials systems via customized R&D and Innovation

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ABSTRACT

Starting with the last quarter of the 19th century until recent modern times, rapidly accelerating technological transformations and developments result in better and superior materials and cause improvements in almost every fields of technology. In this regard, materials technologies are also considered to be one of the major pillars and backbones of modern society with other generic fields such as energy, information-communication technologies and biotechnologies. Starting with the 21st century, a new era for advanced materials has emerged and greatly influenced by the market dynamics and intense competition from new entries (e.g. China and other new competitor countries). Advanced materials engineering has been evolving to become significantly more "integrated materials systems". Working on individual and isolated material components is no longer adequate enough to solve sophisticated engineering problems in industry. Therefore, a new challenge has been forcing advanced materials to become more integrated with variety of materials i.e., multi-materials systems along with interaction of other engineering functions, i.e., multi-functionality. Despite the fact that regularly developing new technical and scientific achievements and improvements, there is a lack of research in technology and innovation management of advanced materials covering its newly forming characteristics in diverse and multi-sectoral markets. The qualitative findings and results of selected 18 contracted projects on advanced materials indicate the emerging rise of collaborative networking and cooperative activities within variety of sectors. It was found that the predominant connections among such activities are with universities, raw materials suppliers, service-providing companies for testing, analysis, characterization and variety of treatments (thermal, mechanical and chemical) along with in-house collaborations for processing and applications. Such findings should be considered new and emerging since the market is very well known for its intensely competitive environment and sensitivity for any spillovers of information of any kind.

1. Introduction

Starting with the last quarter of the 19th century until recent modern times, rapidly accelerating technological transformations and developments result in better and superior materials, called "Advanced Materials" and cause improvements in almost every fields of technology. In this regard, "Advanced Materials" has become one of the important generic technological fields (Kaounides, 1991). Sometimes called as "high performance materials", it is claimed that this group of materials is the "future of every modern society" since they are the basis of all key technologies (Dosch & Van de Voorde, 2001). A general description of advanced materials, in its

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traditional context can be outlined as follows (Baykara, 1998; Kuban et al., 1996): "Materials that are entered the world market in the second half of the 20th Century with considerable scale in the form of 'Advanced Ceramics, Polymers, Metals and Composites' with high purity, high technical performance and high information content with increasing integral function and variety and high added-values". Based on this definition, the classification of advanced materials can be as follows (Fig. 1):

1. Advanced metallic materials
2. Advanced ceramics
3. Advanced polymers
4. Composites: polymer based composites; metal matrix composites; ceramic matrix composites.

In this regard, materials technologies are also considered to be one of the major pillars and backbones of modern society with other fields of energy, biotechnology and information & communication technologies. Due to such characteristics and strong impacts to other technological fields, advanced materials are considered to be one of the generic technologies as well. In its classical scheme represented within the corners of a triangle (metals, ceramics and polymers) and composites along the side lines and at the centre, advanced materials and its multi-technological & multi-sectoral characteristics have unique norms and characteristics such as (Lastres, 1994):

- Research and development (R&D) intensive;
- Generic structure;
- Multi-disciplinary and multi-technological;
- High potential of cumulative effects;
- High cost and high risk investment requirement;
- Accelerating market potential;
- Comparatively long term for development projects;
- Very intense international competition.

Starting with the 21st century, a new era for advanced materials has emerged and greatly influenced by the market dynamics and intense competition from new entries (e.g. China and other new competitor countries). Important characteristics of new advanced materials are particularly focused on their technical functions and multi-faceted characteristics such as physical, mechanical, electrical, optical, chemical and other variety of properties. For many high performance applications, such unique properties along with others (smartness, eco-friendliness, light weight, high strength and durability etc.), advanced materials lead to very high added value products essential for long term profitability and market superiority for firms operating in various sectors such as machinery, manufacturing, microelectronics, transport, automotive, chemical, energy, aeronautical and other industries (UK Technology Strategy Board, 2008–2011).

Rapid advancement of technologies with new scientific results and findings has started to shift advanced materials technologies from its classical scheme towards more integrated multi-materials systems via multi-functional and multi variant characteristics such as physical, mechanical, chemical, electrical, optical and others (Deloitte Global Manufacturing Group, 2012; Yang & Tarascon, 2012). As the traditional disciplinary classification and descriptions fade away, recent advances indicate more integrated multi-materials systems which are now far more effective (Yang & Tarascon, 2012). The traditional classification of materials as represented within the corner of a triangle, metals, ceramics, polymers and composites is loosing its meaning as the evolving and competitive market structures require combined and enhanced properties of variety of materials functioning within a system's integral structure (Maine & Garnsey, 2006).

Newly formed and continuously evolving norms and characteristics of advanced materials will be outlined along with other parallel developments such as innovation models and mechanisms, extensive collaboration through networking and increasing needs of commercialization of innovative R&D results. We will also address these issues from the newly forming unique characteristics of advanced materials and some literature both on the classical and newly forming advanced materials scheme will also be outlined. Thereafter, findings based upon a series of contracted R&D projects conducted during the term of 2007–2012 will be elaborated and qualitative assessments will be discussed based upon the arguments outlined for the new paradigm of advanced materials technologies.

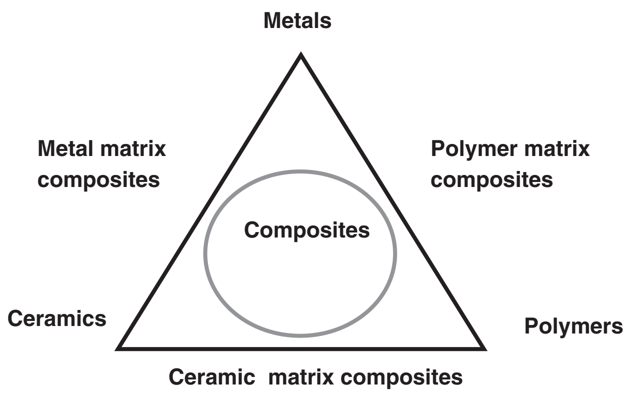

Fig. 1. Classical scheme for advanced materials' classification.

2. A generic transformation of advanced materials technologies

Key challenges of the 21st century in critical fields of energy, environment, defence & homeland security, healthcare, transport, microelectronics, nanotechnology, space & aviation and others are demanding high performance, enhanced properties with multi-functionality from advanced materials engineering. In this sense, an extensive transformation of advanced materials from the classical scheme represented on the corners and sides of a triangle (Fig. 1) indicating a plane and simple classification as metals, ceramics, polymers and composites should be radically changed to a newly formed, complex, integrated and dynamic system. Such transformation of new generation advanced materials system may have the following attributes (Deloitte Global Manufacturing Group, 2012; Federal Ministry of Education and Research (BMBF), 2010; Rooney, Roberts, Murray, & Romenesko, 2000; Dosch & Van de Voorde, 2001):

- High value-added products;
- Multidisciplinary (physics, chemistry, applied mathematics, biology, mechanical, electrical–electronical engineering and others);
- Multitechnological (biosciences, micro-, nano-electronics, photonics, mechatronics, machinery and others);
- Multisectoral (energy, transport, medical-healthcare, sports, food packaging, space & aviation, civil engineering and others);
- Multi-functionality (mechanical, physical, chemical, electrical and others);
- Intelligence and smartness;
- Miniaturization; smaller length scales towards nano-systems.

In its historical context, the materials industry was largely based on substitution of natural materials with synthetic, man-made materials during the first half of the 20th century (e.g., leather by polymeric materials, cotton by synthetic fibres, wood by iron–steel). In the second half of the previous century, materials technologies have shifted from substitution to custom-made materials inquired by the industry (e.g. electronic ceramics for microelectronics, polycarbonate for compact discs). This shift greatly exploited scientific and technical advances following the 2nd World War and brought tremendous advantage and improvement for newly rising industries such as microelectronics, communication, machinery, transport, space & aviation and others. During the last couple of decades, another concept has evolved based upon the needs and necessities of revolutionary market dynamics particularly in the fields of biotechnology, information technologies, nanotechnologies and cognitive systems simply stated as “bio-info-nano and cogno systems”. Other than scientific and technological advances in design, processing, production and quality, governmental policies, market conditions and societal needs and requirements were also effective for shaping and leading advanced materials technologies forward to reach beyond the 21st century (Bauer, 2012; Dosch & Van de Voorde, 2001).

In the traditional approach for manufacturing of materials, design, processing, functions and other factors were outlined in a linear thinking of a series of steps such as, structure; process; properties and performance (Dobrzanski, 2006). A typical engineering design criteria based on such steps can be schematically shown in Fig. 2.

Starting with the late 90s and during the dawn of the new century, emerging scientific and technical advances such as high capacity computational modelling of atoms and molecules to design and tailor new and original compounds for sophisticated functions, rapid advancement of nanosciences and nanotechnologies along with the development of highly capable and effective analytical instruments for testing, analysis and characterization of micro-, nanostructures (e.g. ultrahigh resolution electron microscopes) lead to a new era for advanced materials technologies. Such a large shift within the materials technology is demonstrated in Fig. 3.

This brings newly formed and evolving norms and characteristics for advanced materials such as the following:

- Rapidly decreasing size of materials leading nano-structured materials within atomic/molecular dimensions; it should be noted that nanosciences at atomic/molecular level bring unusual novel properties and changing characteristics.
- Based on these developments, processing, development, testing and fabrication are also getting into the nano level science and technology which bring radical changes in almost whole aspects of materials engineering.
- Accelerating accumulation of knowledge is leading new and quantum-based data storage, communication and diffusion of new techniques and capabilities. New analytical techniques (e.g. high resolution electron microscopy techniques and other advanced imaging and manipulation techniques) and methods in testing, analysis and characterization of materials' properties cause in-depth understanding of atomic and molecular interactions leading new and novel materials synthesis.

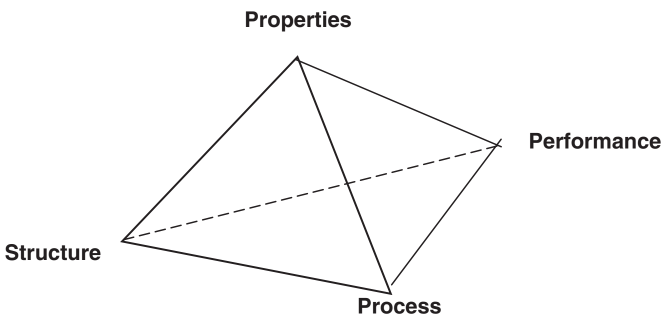

Fig. 2. Relationship within the design of materials.

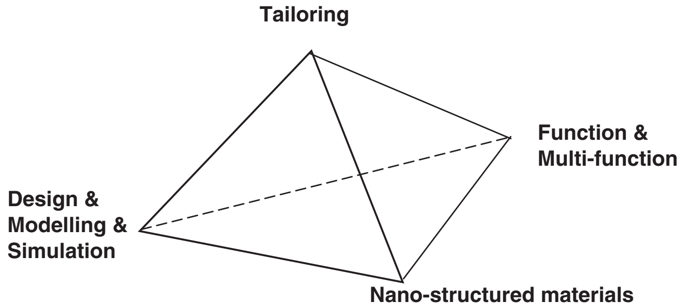

Fig. 3. New relationship within the design of novel materials for the 21st century.

- Already existing characteristics of multi-disciplinary and multi-technological features lead to new emerging fields such as bio-materials, magneto-optical materials, nano-materials, smart and intelligent materials and many others.
- Based upon such emerging characteristics, advanced materials engineering has been evolving to become significantly more "integrated materials systems". Working on individual and isolated material components is no longer adequate enough to solve sophisticated engineering problems in industry. Therefore, a new challenge has been forcing advanced materials to become more integrated with variety of materials i.e., multi-materials systems along with interaction of other engineering functions, i.e., multi-functionality.

Therefore, previous scheme of classification and relationship among some factors of design shown in Figs. 1 and 2 are not valid anymore for advanced materials technologies. New era is strongly demanding complex and dynamic attributes such as innovation and creativity, rapid deployment and commercialization, extensive collaboration in R&D which is becoming R&D and I (innovation), and efficient processing techniques for high quality products (von der Gracht & Stillings, 2013). Therefore, a new and emerging relationship within the design of advanced materials engineering is evolving and shown in Fig. 3.

3. New characteristics of advanced materials technologies

New advanced materials technologies have been considered as key drivers for profitability and growth in 21st century's fast changing environments and severe competition with the new entrants such as China, India and other Asian and Latin American countries (Brasil, Mexico) (Cheng, 2012; Nakagawa, Watanabe, & Griffy-Brown, 2009). Today's high risk, and uncertain market circumstances are demanding new and significantly different novel characteristics. Firstly, innovation and creativity in advanced materials technologies are becoming major cornerstones for almost any organizations. In this regard, collaborative networking in all levels of industrial operations is emerging as a new paradigm for advanced materials (van der Valk, Chappin, & Gijsbers, 2011). Other than scientific and technological advances in design, processing, production and quality, governmental policies, market conditions and societal needs and requirements are also effective for shaping and leading advanced materials technologies forward (Bauer, 2012). R&D intense environment is shifting towards more on R & I (innovation) based operations and R & I is becoming a fundamental economical activity within organizations. It should be noted that more than half of all technical innovations in practically all technology sectors and branches of industry based upon the properties of the materials in use in varying degrees (Ehrenfried, 2012).

As pointed before, the advanced materials sector is largely R&D intensive due to its nature and R&D activities in advanced materials inquire heavy investment with high cost and usually take place in universities, government laboratories and in laboratories of large firms and corporations (Maine & Garnsey, 2006). Other than basic and applied R&D activities in advanced materials, emerging demand for commercialization process inquires extensive R&D including prototype development, pilot plant applications and demonstrative process & product developments along with variety of specific customer demands such as unique testing procedures, and specialty design needs for product & process attributes. The whole R&D stage should be planned towards effective commercialization which is extremely expensive and needs custom-designed R&D processes. Such R&D process should have the following norms and characteristics:

- The whole research activities should be shaped upon the specific demands, inquiries and necessities of the customer. A detailed plan and unique processing including standard and non-standard testing procedures from the start to the end should be carefully designed and coordinated with customers.
- Such customized R&D should eliminate technological uncertainties in the planning stage and an extensive and close interaction with the customer should be coordinated effectively. Specific market norms and characteristics should be taken into account in developing products and processes with the accepted qualifications.
- Customized R&D activities should be conducted with multi-disciplinary expert teams including scientists, engineers, research specialists and capable technical support personnel. In many advanced materials research projects, experts from the fields of chemistry, chemical engineering, physics, mechanical engineering, microelectronics, electromagnetics, software development and others are involved in various steps during the projects.
- A team of market specialists should also be involved during the project activities for more effective commercialization along with IP specialists.

These newly evolving concept of "commercialization" inquires a wholly new understanding of mechanisms within the market, organization and processes such as non-linear perceptions and chaotic system thinking and others. In this regard, more combinatorial (and hybrid) materials systems are modelled through sophisticated software programmes and simulation techniques leading to tailored properties upon customers' demands. The mechanism of innovation and commercialization for advanced materials have a complex and dynamic nature and couldn't be categorized in one of the following models: "market pull" or "technology push" mechanisms. New molecules designed through complex computational simulations and recent hybrid processing techniques are highly advanced and unknown for markets and customers. In this regard, a plane "market pull" mechanism is hard to be operative in many instances. On the other hand, "technology push" mechanism has difficulties in commercialization of any innovative ideas due to high risk, uncertainties and many other complexities. It may take a long delay for any new material innovation to be transferred into a viable product and full commercialization. In this mechanism, high cost and extended duration of research, development and time lag for any product to reach the market are also considered as barriers. Based upon these limitations and problems, the "Technology–Market Matching (coupling)" mechanism has a very high potential in this respect to find new business models and collaborative results in commercialization (Maine & Garnsey, 2006; Maine, Probert, & Ashby, 2005).

Particularly, this mechanism through collaborative networking (local, regional and global) may play a major role for innovative products and processes in materials to reach the market (Maine & Garnsey, 2006). A model based upon a typical value-chain for advanced materials is proposed schematically in Fig. 4.

Collaborations through networking, new business models, new venture capital enterprises, international & global partnership, new ideas such as open innovation networks are all emerging forms and shapes of the advanced materials technologies all over the world (Crabbe et al., 2013; Deloitte Global Manufacturing Group, 2012). As shown in Fig. 4, the whole system of advanced materials should be generated and implemented through innovation networks of interacting and collaborating organizations and individuals. Based upon these evaluations, one may conclude that the system of innovation and any advanced materials product in reaching the market is functioning in a complex and dynamic manner of combinatory mechanisms of "technology push", "market pull" and "technology–market matching (coupling)".

In the following section, the findings of a series R&D projects conducted and completed within the term of 2007–2012 on high technology advanced materials systems are assessed according to this model. Typical features of newly advanced properties and novel characteristics of advanced materials within this changing environment will also be outlined.

4. Methodology & findings

The qualitative data for analysing the context of new advanced materials system outlined in Fig. 4 was originally gathered from a series of research and development projects on advanced materials conducted in between 2007 and 2012. These contracted R&D projects were partly the outcomes of a large state (the State Planning Organization) and internationally funded (the World Bank) programmes on advanced materials. A complete infrastructural background for processing, shaping, treatment and testing was provided through these programmes. More detailed information could not be given due to commercial and other classification types for these projects. However, typical characteristics of the projects including the types of R&D, technology, customers, sectoral profiles, innovation and creativity involved through the studies, networking and collaboration and form of commercialization are being investigated and discussed within the model given in Fig. 4.

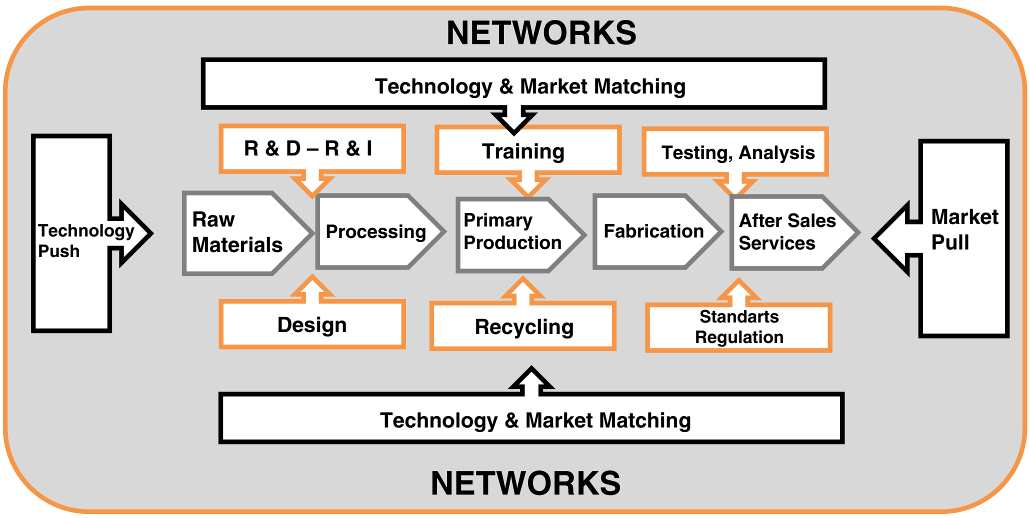

Fig. 4. Advanced materials value chain and innovation & commercialization mechanisms.

Based upon the programmes' objectives, advanced materials were defined as the materials systems differing from its already known classification and description to a new level of combining a variety of materials including metals, ceramics, plastics and classical composites (metal matrix, ceramic matrix, polymer matrix) and their processing techniques including novel hybrid formation via specific bonding and interface engineering techniques.

Selected 18 (eighteen) projects were completed in the Materials Institute of leading RTO of Turkey, TUBITAK (Turkish Scientific and Technological Research Council), and MRC (Marmara Research Center). Table 1 shows the types and typical characteristics of these projects.

Objectives of the projects have varying purposes ranging from particular-specific applications, component development, processing to general applications. It should be noted that the majority of the projects are customized R&D projects and projects' objectives were planned with the experts assigned by the customers. Such a wide range of R&D subjects shown in Table 1 is a typical characteristics of advanced materials due to their specific properties including light weight, high strength, durability, corrosion resistance and toughness along with special functions such as protection, sensing, electromagnetic properties, acoustical properties, and filtering. Thorough testing and characterization as one of the major steps in these projects were demanded by the customers for certain qualifications and in some projects, specified novel testing procedures were designed for the measurements of special properties, features and functions for the developed end products.

Innovative ideas by the service providing sub-contractors, universities, and suppliers were also inquired and exploited in such cases for such particular testing and performance measurements and evaluations. In this regard, an effective network of various actors was actively involved in projects. These actors include the following

- universities,
- service providing small companies,
- sub-contracting companies,
- in-house testing service and design providers,
- supplier companies,
- designer and software development companies.

Table 1
Type and characteristics of the projects.

	Industry & technology	Size	Type
1	Defence & homeland security; advanced materials with unique electromagnetic properties	L	Applied R&D covering the whole range of synthesis, processing, application and field tests; high tech
2	Defence; advanced materials with unique electromagnetic properties	L	Customized R&D; full system integration covering prototype application and field tests; high tech
3	Defence; advanced materials with unique acoustical properties	L	Customized R&D; full system integration covering prototype application and field tests; System and product development; high tech
4	Defence & homeland security; advanced materials system with unique sensing properties and filtering	L	Customized R&D; full system integration of different advanced materials system (sensing + filtering) covering the whole range of synthesis, processing, application, prototyping and field tests; high tech
5	Defence & homeland security; advanced composite materials system	L	Customized R&D; full system integration covering processing, prototyping, application and field and environmental tests; high tech
6	Integrated composite materials system covering whole materials range transport and construction	L	Applied technology to cover the whole processing steps; prototyping, application and extensive field tests; Product development; high tech
7	Advanced composite material component; transport sector	L	Customized R&D covering the whole synthesis and processing steps; prototyping, application and extensive field tests; Product development; medium tech
8	Homeland security; advanced materials system for critical sensor applications	L	Customized R&D covering the whole synthesis and processing steps; prototyping, application and extensive field tests; high tech
9	Homeland security; advanced materials system for critical sensor applications	L	Customized R&D covering the whole synthesis and processing steps; prototyping, application and extensive field tests; high tech
10	Defence & homeland security; advanced materials with unique electromagnetic properties	L	Customized R&D covering the whole range of synthesis, processing, application and field tests; high tech
11	Advanced composite material component; Security and protection	S	Customized R&D; adaptation of technologies, application and extensive field tests; product development; high tech
12	Homeland security; advanced materials and advanced textiles with multi-functional properties	L	Customized R&D covering the whole synthesis and processing steps; prototyping, application and extensive standard and field tests; high tech
13	Defence and homeland security; advanced materials and advanced textiles with multi-functional properties	L	Customized R&D covering the whole synthesis and processing steps; prototyping, application and extensive standard and field tests; product development; high tech
14	Transport industry; special coating with multi-functional characteristics	L	Applied R&D covering the whole range of synthesis and processing steps; application and extensive standard and field tests; high tech
15	Environment; advanced materials for critical sensing capabilities	L	Applied R&D covering synthesis and processing steps; application and extensive standard and field tests; high tech
16	Advanced composite material component; Security and protection	M	Customized R&D; adaptation of technologies, application and extensive field tests; product development; high tech
17	Construction and building; Advanced composite materials	S	Applied R&D covering application and extensive standard and field tests; medium tech
18	Construction; advanced composite materials	M	Applied R&D covering application and standard and field tests; product development; medium tech

Note: L: Large; M: Medium; S: Small.

The size of the projects is classified as follows: L: Large size projects, duration min. 2–3 years, budget above 2 million USD; M: Medium size projects, duration 1–2 years, budget 1–2 million USD; S: Small size projects, duration max. 1 year, budget less than 1 million USD.

Type of the projects reflects recent customer inquiries covering the whole range of steps including synthesis, development, application and thorough testing. Thorough testing implies the whole range of analysis, testing and characterization of materials properties and performances according to standards and norms. Majority of the projects have also dealt with customized field tests demanded for the prototypes. In Table 2, a qualitative questionnaire card for the assessment and evaluation of projects is shown for identifying various aspects, types, classification and characteristics of projects under investigation.

Some of the major results and findings on the 18 projects are summarized and listed as follows:

– Majority of the projects under investigation can be viewed as high-tech materials system project due to the nature of processing techniques (new, novel, sophisticated), multi-functionality (durability, light weight, special functions), testing-performance and other features. Some projects have medium-technology characteristics.
– Functional materials system development was the major emphasis within the projects and particularly integrated materials system as the nature of materials was chosen to combine various materials ranging from particulate ceramics, metals–alloys, polymeric substances, specialty bonding agents, advanced textiles, and novel chemicals treating interfaces in between different materials to many others.
– Number of personnel involved in customized R&D projects averaged 15–20 experts including researchers, engineers, technicians and other supporting staff. Other than advanced materials technologies, certain engineering disciplines were also involved for the system integration and testing of products developed through the projects and treated as "platforms" to combine variety of functions and unique characteristics. These disciplines are mechanical engineering, chemistry, chemical engineering, physics, microelectronics, software development along with other experts from mould design & development, ballistics, munitions, paints,

Table 2
Questionnaire card for the assessments and evaluation for the projects.

Type of technology	- Low - Medium - High	- System - Component - Process - Testing
Customer profile	- Large corporation - SME - State - Others (foundation, non-profit civilian organizations)	
Functional characteristics	- Mono-functional - Multi-functional - Specific function	
R&D type	- Basic science - Applied - Technology development with prototyping	
Scientific profile	- Mono-disciplinary - Multi-disciplinary	
Sectoral profile	- Metals - Machinery - Electronics - Ceramics - Textile - Healthcare	- Energy - Transport - Environment - Automotive - Others
Innovation & Creativity	- Innovative & creative ideas exists OR not - Type of innovation: On basic value chain OR supporting actions	
Testing and characterization types	- Standards and norms - Specific testing procedures - Novel testing	
Networking & Collaboration (as # of actors involved)	- University - Sub-contractors - International	- Suppliers - Partnership
Critical Performance	- Not important - Important - Very important - Critical	
Patents & Intellectual property	- Patent application exist OR not - Exploitation of already existing patent or not - Not an issue	
System integration	- Isolated, sole components - Sub-system integration - Full system integration	
Commercialization	- Licensing - Technology transfer - Collaboration - Others	

radiophysicists, acoustics, electromagnetics and civil engineering. This certainly indicates the multi-disciplinary and multi-technological characteristics of the advanced materials technologies.

– The major customers for the projects were state organizations and institutions along with some SMEs and firms of municipal governments.
– Majority of the projects aimed for materials systems development for multi- and/or specific-functional products for applications as 1:1 prototypes and products (in some cases a limited manufacturing were also demanded).
– Sectoral profile reflects the recent shift from regular sectors of metals, ceramics, and plastics to a more diverse sectoral distribution of defence, homeland security, security, transport, environments, and construction.
– Majority of the projects had used creative and innovative ideas and novel applications within the synthesis and processing techniques, interface manipulation, bonding, special chemical treatments, prototype development and unique field testing. It should be noted that the majority of the innovative ideas for project activities were initiated by the collaborating participants, particularly suppliers, service providing small companies and academicians.
– All the projects were conducted collaboratively through a diverse environment and networks including (active participants ranging 4–10 were involved in projects):

  • Universities;
  • Other departments and divisions of the organization (in-house collaboration);
  • Sub-contractor companies and organizations;
  • International organizations;
  • National and international suppliers;
  • Project's contracted partners.

– As pointed above, these collaborating partners within the networks of the projects were dynamically eager to come up with innovative ideas to ease the challenging problems of the project studies.
– Expected performances of the developed materials systems were ranging with varying degrees of very important-to-critical. Majority of the projects had resulted in original and novel ideas and lead to legal intellectual property procedures.
– Due to extensive collaboration with the customers and other participants, commercialization procedures were mostly through "collaborative technology transfer". The nature of advanced materials including complicated synthesis and processing steps and needs of complex testing, analysis and characterization techniques force the customer to be involved in transferring the technology within the consultancy and participation of the projects experts. In this regard, just a plane "technology licensing" process would not be sufficient for the customer to absorb the whole technology.
– Only one project given in Table 1 (Project No. 11) dealt with the development of a sole composite component using variety of synthesis and processing techniques. All other projects were aimed to develop "materials systems" using a variety of unique materials (multi-materials) and integrate them onto products with engineered interfaces of individual components. In such investigations, a complete design and optimization of interfaces using modelling techniques such as microstructural design, tailoring of properties, atomic/molecular computation and simulation and others were extensively utilized (Dobrzanski, 2006; Sirisalee, Ashby, Parks, & Clarkson, 2006; Yang & Tarascon, 2012).

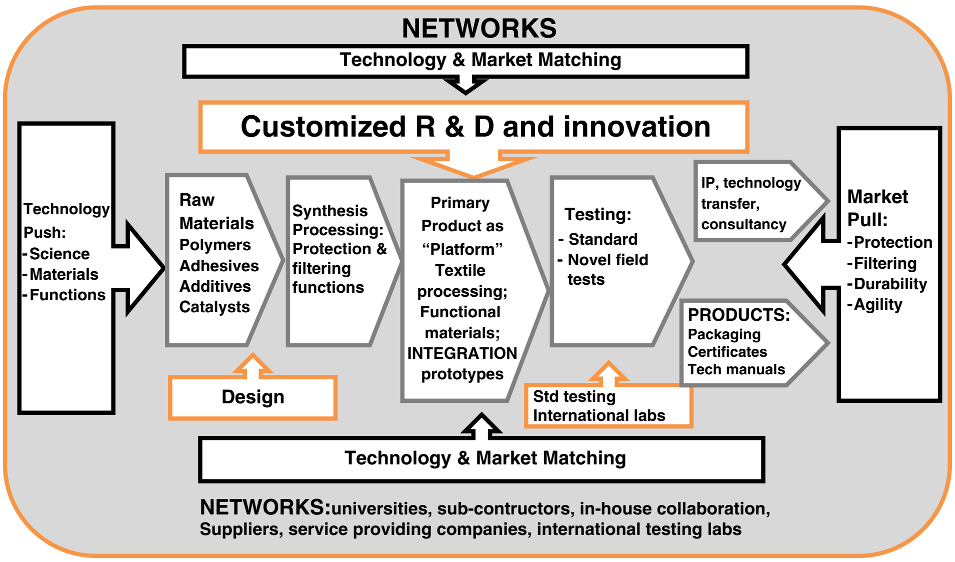

Fig. 5. A case project: integrated multi-materials system value chain and innovation & commercialization mechanisms via customized R&D and Innovation.

4.1. A case project for the model

The model based upon the value chain and innovation & commercialization mechanism given in Fig. 4 is adapted for one of the projects given in Table 1 (Project No. 12) and is shown above in Fig. 5. The aim of the PROJECT was to develop a unique textile product which should be durable under severe environmental conditions and also functioning as a filtering media for challenging environments. The product was designed as a "platform" at the start of the project and a detailed specification and a list of conditions were prepared and agreed upon a specific test acceptance document. Experts of customers were in close contact during the course of the project to monitor the given requirements, demands and expectations. In this sense, the whole project was designed as a full customized process from the very start to the end.

Science of polymer synthesis, advanced carbon materials technology and unique textile processing techniques as the "technology push" factors were all combined and used in harmony to come up with the platform performing under the given conditions. A high and critical demand for protection and filtering of severe and dangerous environments may be evaluated as the "pull" factor for the project. Based on the value chain starting with specialty polymeric materials, additives, catalysts as raw materials, sophisticated synthesis and processing techniques were utilized to obtain the needed functional advanced materials and mounted onto textile surfaces using novel adhesion techniques. A thorough testing plan is accomplished and most of the tests were performed at the international testing laboratories abroad and certified test results were obtained. A series of participants as part of the collaborative network including polymer scientists from universities, raw material suppliers, textile experts, mechanics, international testing labs, in-house testing experts and other service providing small companies was involved within the project. Considering the whole process outlined above, a clear indication of being an "integrated multi-materials systems" through the customized project's activities may be seen in the integration of the following sub-components:

- Advanced synthesis of polymers and specialty heat treatment
- Advanced carbonization techniques to obtain designed microstructural features (nano-sized interconnected porosities with very high surface area)
- Novel adhesion techniques to mount advanced materials onto textile surfaces
- Design and development of specialty textile platforms
- Standard and non-standard novel testing, analysis and characterization
- Many other sub-components of the system.

At the end of the project, a complete "technology package" (the term is offered by the customer) along with the prototypes with certificates and technical manuals was prepared and after a thorough review by the customer, the project was officially accepted as "completed". A couple of patents was prepared and submitted and granted following the completion of the project and used during the "collaborative technology transfer" procedures.

5. Discussion and conclusion

As pointed out before, despite the fact that regularly developing new technical and scientific achievements and improvements, there is a lack of research in technology and innovation management of advanced materials covering its newly forming characteristics in diverse and multi-sectoral markets. Such factors can be classified within the following basic headlines as:

i. Innovativeness & creativity;
ii. Advanced materials as integrated multi-materials systems
iii. Collaboration & networking;
iv. Critical performance & multi- and/or special-functionality;
v. Challenge of commercialization.

As indicated before, since advanced materials technologies carry challenges both in market and in technological (high risk, uncertainties, long duration of research, high cost of investment etc) innovation mechanism is categorized along the market–technology matching (coupling) model. Qualitative data gathered from 18 projects reflects customer's specific demands on materials synthesis, processing, prototype development and complete testing, analysis and characterization procedures along with novel performance measurement techniques and field tests. In each of these steps, innovative ideas and solutions were inquired from those networking actors of universities, sub-contractors and even from suppliers (specifically chemicals, bonding agents, interface treatment substances etc). In this regard, highly complex innovation dynamics were observed during the projects' activities. This should be considered as one of the emerging faces of new advanced materials technologies particularly in integrated multi-materials systems. Most of the innovative ideas and applications involve extensive collaboration through the triple cooperation of university–industry–research institution to come up with novel solutions based upon scientific and technical findings.

The qualitative findings and results of selected 18 contracted projects indicate the emerging characteristics of new advanced materials system as rising of collaborative networking and cooperative activities within variety of sectors. It was found that the predominant connections among such activities are with universities, raw materials supplier companies, service-providing companies for testing, analysis, characterization and variety of treatments (thermal, mechanical and chemical) along with in-house collaboration for processing and applications. Such findings should be considered new and emerging since the market is very well known for its intensely competitive environment and sensitivity for any spillovers of information of any kind.

Customer's demands had focused on the critical performances of materials systems developed through almost all of the projects and thorough testing, analysis and characterization procedures by accredited laboratories were inquired. A variety of different materials along with other constituents as integral entities within the platforms developed through project activities was expected to carry specific functions (mechanical, physical, chemical, acoustical, sensing, electromagnetic and others) during their applications under severe conditions and environments.

The majority of customers' demands and desires for materials (for both products and processes) based upon the projects' findings can be listed as follows:

- Decreasing size and weight is the predominant inquiry;
- Almost all organizations desire to be innovation-centric and seek for creative solutions in all levels of operations.
- Functionality within the same material's platform is a must and integrity is primarily demanded.
- High value added products are the major targets of organizations.
- Lowering cost and high volume production are secondary concerns.
- Collaborative networking is extensively emerging and many firms are seeking for reliable and efficient university collaborations.
- Major areas of interests in advanced materials: tailored materials; smart/intellectual systems; nano-structured materials (as functional coatings); functional materials systems.

Based upon the findings and observations through these projects, a new approach and understanding for advanced materials complex depicted as "integrated materials systems" may reflect the following attributes:

- In such materials complexes, one may not consider materials as simple and plane elements and/or sub-elements of a system. The system itself is a new advanced materials platform as an integral entity developed for specific functions with multi-variant properties and characteristics.
- Emerging new models for advanced materials are based upon combining and putting all together the variety of sub-fields of materials science and many other engineering fields (chemical, mechanical, microelectronics, software etc) to solve the challenging problems with such "integrated systems materials engineering".
- Such a complex materials system may not be developed by single and/or limited actors, an extensive collaborative networks should be developed for innovative materials system. Actors of networks should include a range of actors from varying fields and sectors.
- University, and academia involvement must be unseparable actors for such networking for the scientific and technological framework for the development of new advanced composites.
- High risk and high cost of investment and maintenance for processing, testing, analysis and characterization during the R&D and innovation stages may be solved by directing such investments to professional research and technology organizations (RTOs). Such RTOs may play a central role in variety of networks as service providers in processing, testing, analysis and characterization along with other tasks such as sub-contracting and consulting as well as collaborative partners.

As for the commercialization of the project's outcomes, unknown risks, high cost of investment, market uncertainties, and complex nature of advanced materials (includes synthesis, processing, design, development and testing all together) reflect the challenging nature of the commercialization from the very start to the end. As pointed above, simplified "licensing" may not be the correct path due to complicated technical details which may cause dead-ends during the production. Therefore, collaborative technology transfer is suggested for such procedures as given in the case project above. Extensive close collaboration of the critical project team with the customer's production staff has resulted better and far more faster achievements during the start of the production.

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