CAREERS IN MATERIALS ENGINEERING

LEADERSHIP ROLES FOR MATERIALS ENGINEERS STEADILY EVOLVING: ARE YOU READY?

Today's materials engineering leadership role is expected to expand and have a greater impact on evolving the organizational, technological, and strategic initiatives of original equipment manufacturers.

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The number of materials engineers is not expected to significantly grow in the future, but their influence on the way materials are selected, used, sourced, and manufactured in a company will undergo a structural shift with considerable business impact. Further, the scope of materials engineering leadership will broaden from component and subsystem level work to influence on product, strategy, and business goals. This evolution together with technology megatrends such as materials analytics, modeling, optimization, and Industry 4.0 (IoT) will significantly transform the conventional view of the materials engineering function as a quality sub-function—with emphasis on experience and experiments.

CURRENT STATE

Direct material cost is the highest cost item for an original equipment manufacturer (OEM) of automotive, agricultural, and construction equipment. Four significant OEM materials decisions include:

1. Materials research (introduction of new materials or process)
2. Materials selection for a component or assembly
3. Materials processing
4. Materials sourcing

However, only one of these decisions is driven by materials engineering in OEMs (Table 1). Unfortunately, the role of materials engineering is reactionary in many of these decisions, i.e., fixing wrong materials decisions made by other functions. Even the introduction of new materials or processes, which is typically performed by materials engineering, requires synergy and maturity of design, supply management, manufacturing, and quality functions for transitioning to business.

Traditionally, the OEM materials engineering function has 4E characteristics: (1) expertise and experience based decisions, (2) experiment based decisions, (3) emergency problem solving, and (4) external supplier dependency. Most materials engineering decisions are derived from functional experience plus laboratory and shop-floor experiments. Materials engineers are continually "putting out fires" on product issues in the field or at the customer (failure analysis) and on the manufacturing line due to this reactionary approach. Many of these issues are attributed to decisions made at an earlier stage of design, manufacturing, and procurement without appropriate materials engineering input. With today's increased emphasis on outsourcing, there is greater dependence on external suppliers for many key materials processes and workflow decisions, resulting in a loss of important OEM competencies and skillsets. Further, materials engineering functions operate primarily at the component or subsystem level, resulting in limited influence and impact.

IMMENSE POSSIBILITIES AND BUSINESS IMPACT

New skillsets and an encouraging environment provide an unprecedented opportunity for materials engineering

TABLE 1 – KEY OEM MATERIALS DECISIONS AND RESPONSIBLE FUNCTIONS

Key materials engineering decisions	Function driving decision
Materials research	Materials engineering
Materials selection	Design function
Materials processing	Manufacturing engineering
Materials sourcing	Supply management function

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leadership to have an impact on all four OEM materials related decisions. Some possibilities and real examples follow.

Materials research. Generally, the OEM materials engineering R&D team is responsible for identifying appropriate opportunities to introduce new materials and processes to the organization. The challenge is to identify newly mature technologies and specific components and processes that could impart business value. Mere generic identification of technology trends, e.g., nanomaterials, additive manufacturing (AM), or lightweighting, is not sufficient for successful adoption by the organization. For example, although AM is near the required maturity level for business implementation, the challenge lies in specific organizational opportunities where it can be successfully implemented with sufficient value. Even at current manufacturing cost levels, AM has been successfully leveraged in low-volume, high-performance critical aerospace components that cannot be produced using traditional manufacturing methods. Other AM applications include low-volume production parts made without investing in tooling costs, producing agriculture machinery parts, rapid prototyping in product development, and making tool fixtures.

Another factor to consider before adopting new materials or processing technology is the simultaneous maturity of all associated functions[1]. Bottlenecks for technology adoption many times are due to functions other than materials engineering. For example, adopting nanobainitic steel (a steel with extraordinary strength and ductility) requires a designer's acceptance for a specific application, a structural analyst's acceptance in terms of materials properties and failure criteria, acceptance of materials standards and quality criteria, the OEM's ability to form and handle this high strength material, and possibly the most difficult aspect of ensuring a supply chain to scale up the use of the special material at an acceptable cost (Fig. 1).

Similarly, adopting adhesives to replace welded structures requires changes in the OEM manufacturing line with guidelines for failure criteria and analytical procedures. Structural applications of carbon fiber-reinforced composites include high-end sports cars, boats, and aerospace components. Carbon-fiber composites are also used in agriculture machinery, such as self-propelled sprayers with higher boom width. The lightweight structure results in significant weight reduction, enabling a 25% increase in sprayer tank capacity, which enhances productivity. High customer value justifies the use of this expensive material.

Product engineering. Emergence of integrated computational materials engineering (ICME) provides opportunities for the materials engineering function to have an impact on OEM product development. ICME is a computational framework that integrates design, materials, and manufacturing during product development and creates value at their point of juncture (Fig. 2). Value creation arises from engineering realization through an accelerated development cycle and/or reduced product cost[2].

ICME has been leveraged for functional design of specific alloy grades and functional coatings, as well as design optimization. The approach can be leveraged at multiple scales including efficient design of specific components. Figure 3 shows an integrated ICME framework, where design, process, and product verification phases are coupled to realize an optimal, robust component[3]. In the framework, design and FEA steps are combined with the correct tooling and process for the purpose of optimization, which significantly reduces the design-FEA iteration cycle and enables optimal product design. Further, cost and performance are incorporated for a holistic design to evaluate multiple materials and design concepts. Instead of the prevalent heuristic approach, the framework also provides opportunities for rational materials and process selection for a specific component, resulting in significant cost and weight reductions in castings, welded fabrications, and heat treated components. For example, Fig. 4 shows a tractor production part optimized through this approach, with ubstantial cost reductions and attractive ROI.

Further, ICME predicts and includes effects of the manufacturing process (e.g., residual stress from carburizing or shot peening) in the design stage for optimal, robust components

Fig. 1 — Multifunctional maturity is required to successfully adopt new materials and processes.

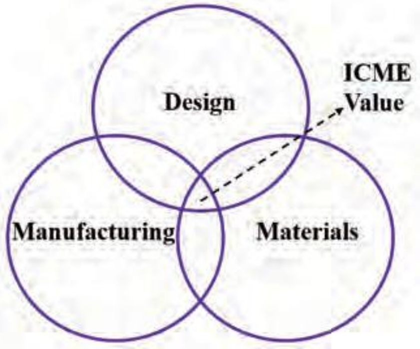

Fig. 2 — ICME value creation at the junction of design, materials, and manufacturing through a computational framework.

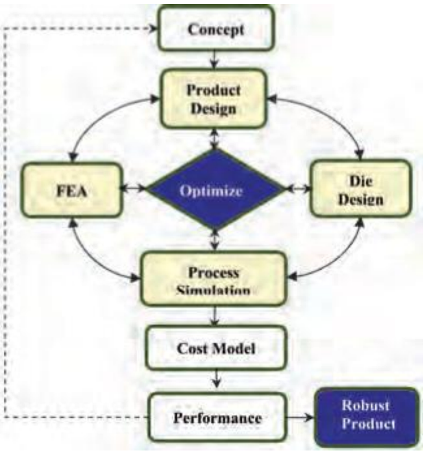

Fig. 3 — Integrated framework for design optimization including simultaneous materials and manufacturing considerations[3].

Fig. 4 — Production part for a tractor developed through design optimization and rational materials selection.

(Fig. 5). Considering the improvement in fatigue life due to residual compressive stress, this active feedback approach in the design phase could result in weight reduction of 12% for a carburized shaft and 5-8% for a shot peened shaft[4]. Another example of product impact is the development of a sugarcane harvester from system level modeling of wear mechanisms, understanding of a materials wear map, and machine-crop interactions[5]. This industry-leading innovation is expected to significantly reduce wear on the harvester cutting blades—the second highest operating expense after fuel costs[6].

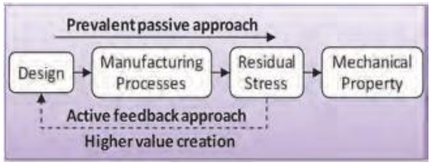

Fig. 5 — Active feedback loop for anticipating and incorporating manufacturing-induced changes in the design process for robust, optimal products[4].

Other possible impacts of product engineering include rationalizing materials grades and thicknesses and developing specific ground level application maps for materials, processes, and treatments. These solutions must be deployed appropriately in the product development cycle, PLM tool sets, standards, and designer guidelines so that manufacturing can be systematically scaled up to create significant value.

Manufacturing operations. A significant amount of material, process, production, and quality data is generated in modern manufacturing operations, which are primarily used for process audits and troubleshooting specific batches with quality issues. These rich data sets can be better used to generate insights for process optimization to improve manufacturing efficiency and product quality for overall reduction in operating costs (Fig. 6).

Big data, data analytics, and data-based modeling approaches (neural network, principal component analysis, and other advanced statistical methods) are emerging to analyze manufacturing operations. The effectiveness of this approach is described in the literature[7], where manufacturing data together with domain understanding are synthesized with physics and data-based modeling approaches to generate insight for process optimization and control. This work results in tangible business value in terms of enhanced operational productivity, proactive furnace maintenance, recipe rationalization, and operational cost reduction.

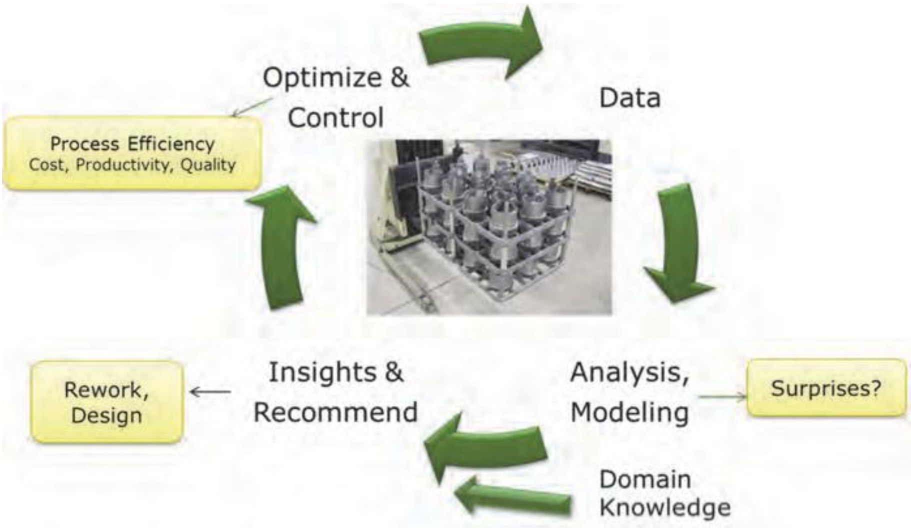

Fig. 6 — Approach to process analytics, integrated modeling (data and physics based), and optimization for industrial processes[7].

Further, the emergence of Industry 4.0 can have a significant impact on materials processing operations such as heat treatment[8] and foundry operations. The most significant difference would be a mindset change in considering the heat treating process as part of the connected production operation instead of the prevalent silo view. A connected gearmaking process is illustrated in Fig. 7.

Heat treating data, which is typically used for quality audit purposes, would be leveraged to provide part-level data-sharing for improved pre- or post- operations. Transferring specific data (e.g., chemistry data from the steel mill and casting) could provide better control of reheating, annealing, and carburizing operations, which in turn would help mitigate or manage distortion in these precision components. Also, identifying the location of specific components in batch type operations would help to design better recipes for machining and finishing operations. Such individualized solutions at the part level would bring transformational change to quality control at the product level. One of the biggest changes in the heat treating operation is recipe management, which is now heuristically driven. The large amount of production and quality data and their mathematical models would help in developing self-learning and self-evolving heat treating recipes, suiting current production and quality needs with due consideration of current furnace health and operating conditions. When aligned with the overall Industry 4.0 vision, these changes would also make heat treating operationally efficient with robust quality products.

Supply management. Materials engineering could play a significant role by providing strategic input to the materials-sourcing and supply-management

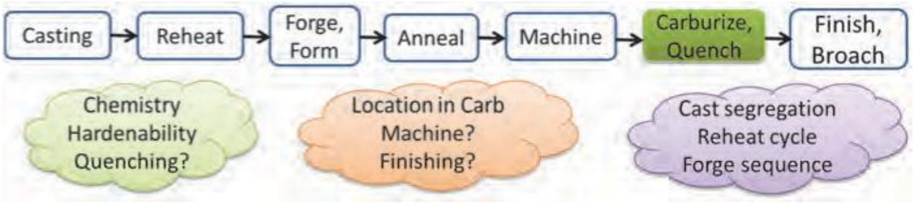

Fig. 7 — Process chain for gearmaking, also showing the way heat treating operations are integrated into the chain[8].

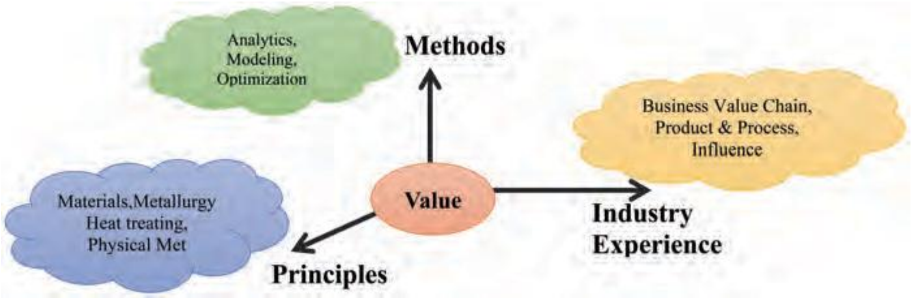

Fig. 8 — Modern materials engineering competencies needed to be successful within an OEM.

function. In multinational companies with global operations and multiple product platforms, the supply chain network is very complex. Materials engineering could strategically support the standards group in rationalizing material grades to be used for all products. In addition, by identifying equivalent local grades at key supply chain nodes, substantial cost reduction can be achieved without incurring special grade material cost. Further, advanced analytics can identify similar parts, comparing specific costs and detecting cost-outliers with structural reduction in direct materials cost.

Another issue is that commodity prices of different materials undergo significant price fluctuations. For example, during the past decade the price of nickel (a key element of drivetrain steel grades) nearly tripled and then fell back to lower levels. Materials engineers could create dynamic preferred materials grades with criterion on material cost cutoffs to trigger alternate grades during a high commodity-price cycle, acting as a safeguard against commodity pricing swings. Multifunctional synergy among supply management, IT, and materials engineering for a strategic shift in data- and knowledge-based sourcing strategy could unlock unprecedented OEM business value.

DEVELOPING FUTURE TALENT

As mentioned previously, future materials engineering teams can significantly influence and impact OEM business results. However, different competencies and skillsets must be developed. There is a significant shortage of skilled engineers in conventional areas (materials selection, physical and mechanical metallurgy, casting and solidification, heat treating, powder metallurgy, ferrous and nonferrous metals, polymers and elastomers, composites, and special materials), which are needed for successful OEMs. These foundational capabilities must be revisited with respect to new perspectives of analytics, modeling, optimization, IoT, and Industry 4.0 framework. Also, a solid understanding of the business value chain, product, and associated functional influence is necessary to be successful in a leadership role. Such a skillset transformation (Fig. 8) would make materials engineering more contemporary and exciting, and help with effective management of functional knowledge with an enhanced impact on the organization.

SUMMARY

The materials engineering leadership role within OEMs is expected to transform into a role of influencer for materials research, product engineering, manufacturing, and supply chain. This requires new skillsets and competencies regarding analytics, modeling, and optimization, which would supplement the conventional approach of experiments and experiential problem solving. Leadership focus should aim for proactive identification of opportunities to bring structural changes in the way materials are selected, specified, used, manufactured, and sourced within OEMs, which will have an unprecedented impact on business. **~AM&P**

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