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Material Qualification in the Automotive Industry

CAR
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INTRODUCTION

The recent emphasis on fuel economy is expected to accelerate the evolutionary rate of introducing lightweight materials. CAR's Coalition for Automotive Lightweighting Materials (CALM) group identified material qualification as one of the major barriers to faster introduction of lightweight materials in an automobile along with other barriers such as joining technology, traditional paint-shops, availability of simulation tools, and global supply-chain.

The purpose of this whitepaper is to highlight opportunities to reduce the material qualification barrier for faster introduction of advanced lightweighting materials such as high strength steel, aluminum, plastics and polymer composites and magnesium into the vehicle. Material qualification is a process that takes place between a material supplier and the customer (usually an automaker for tier 1 suppliers). The objective is to make sure that the materials meet the requirements set by the customer. The qualification process involves a series of iterative steps until the customer approves the supplier's material to be considered in its future products.

Material qualification differs from material development and material verification. Material development is the development of a new material not in existence before. This may be triggered by product or market requirements. The development process is followed by the qualification process. Material verification, on the other hand, is the process of making sure that the material used is the right one.

For this study, Automotive experts working with material suppliers and OEMs, who are involved at various stages of the qualification process were interviewed. The titles of these subject matter experts range from material engineer to technical specialist, and product manager to vice president. This paper summarizes the interviews and discussions conducted on the topic by the CAR team to document the material qualification process and identify opportunities to facilitate faster introduction of new materials.

The project was driven by CALM which is a working group comprised of more than 30 material producers and fabricators. The purpose of the coalition is to support the cost-effective integration of mixed materials to achieve significant reduction in vehicle mass through the collaborative efforts of the materials sector and automotive manufacturers. CALM contributors played an important role in this research paper. The CALM meetings served as an opportunity for CAR researchers to clarify the challenges of transitioning from conventional to an automotive lightweighting materials supply chain. Many CALM participants gave generous time through interviews to further refine the direction of this research. These interviews provided a rich source of information on the materials, processing and fabricating technologies.

PUSH FOR NEW MATERIALS AND NEED FOR MATERIAL QUALIFICATIONS

New materials with better performance characteristics are introduced into the vehicle for various reasons, but primarily for improving crashworthiness, noise and vibration, overall cost, and fuel economy. The National Highway Traffic Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA) issued the joint final rule[1] in 2012 extending the National Program to further improve fuel economy and reduce greenhouse gas emissions for passenger cars and light trucks for model years 2017 through 2025. The rule established a requirement of a combined fleet-wide fuel economy of 40.3-41.0 mpg for 2021 and 48.7-49.7 mpg for 2025.[2] EPA's GHG standards, are projected to require 163 grams/mile of carbon dioxide (CO_2) in model year 2025 (equivalent to 54.5 mpg if the vehicles were to meet this CO_2 level solely though improvements in fuel efficiency). To meet the regulatory fuel economy requirements and improve performance, automakers will need to lightweight their vehicles. Estimates indicate that a 10 percent reduction in mass can result in approximately a 6 percent increase in fuel economy.

Earlier CAR research "Assessing the Fleet-wide Material Technology and Costs to Lightweight Vehicles"[3] shows that the rate of material technology improvement (growth in use of lightweight materials) between 2007-2015 is 3.8 percent per year for cars and 6.8 percent per year for body-on-frame vehicles. This pace of material technology improvements is expected to accelerate in the next decade due to regulatory pressure. Figure 1 shows general trend in automotive material technology. By 2025, the U.S. fleet is expected to be net 5 percent lighter (after adjusting for mass add-back[4]) by use of advanced high strength steel in body-in-white, all aluminum closures, magnesium in interior structural components like instrument panel crossbeam, and incremental advancements in plastics and polymer composites. Composite material offers significant weight savings (as much as 50 percent) compared to steels and potential for complex designs with part consolidation, but are expensive to source and repair. For high performance, upper market vehicles, automakers may introduce composite materials like carbon fiber in the body-in-white and closures to maintain the performance and offset the weight add-back.

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[1] 49 CFR Parts 523, 531, 533. et al. and 600, 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule

[2] NHTSA is required by Congress to set CAFE standards only five years at a time, but presented the non-final "augural" standards for 2022-2025. Final CAFE standards for MYs 2022-2025 will be established by NHTSA in a future rulemaking.

[3] Baron, J., and Modi, S. (n.d.). Assessing the Fleet-wide Material Technology and Costs to Lightweight Vehicles (Rep.). September, 2016, CAR website.

[4] Lightweighting the vehicle causes safety, noise, vibration, and harshness (NVH) issues. Some weight needs to be added to account for safety, NVH, performance, and other customer requirements. CAR research suggests that approximately 5 percent of the curb weight of the vehicle is added back.

Before a material can be sourced from a supplier, it needs to pass through a series of steps called the material qualification process. Qualification of a material or process is needed when a current material or technology needs to be replaced or improved in an existing application while maintaining or improving form, fit, and function and to define business case aspects with high confidence. It is also needed when incorporating new material or technology into a new product or application. Managing material qualification involves multi-discipline, multi-functional experts who can take into account product, process, and customer requirements. The goal of the qualification process is to establish feasibility of use, demonstrate applicability, address supply chain risks as well as concurrent workforce development. The process of qualifying the materials is important to the automaker because vehicle safety and performance expectations are always high from the customer. A part failure in a running vehicle can risk lives and prove costly for the automaker due to recalls and legal issues. The material qualification process is explained in the following section.

Figure 1: Trends in Automotive Material Technology

Material	Examples	Typical Usage	Trend
Conventional Steels	Mild Steel	High formability parts like fender, door outer/inner	↓
High Strength Steels (>300 Mpa UTS)	Bake Hardened steel	High formability parts	↓
Advanced High Strength Steels (>500 MPa UTS)	Dual Phase steels	Structural members	↔
Ultra High Strength Steels (>700 MPa UTS)	Hot Formed (boron)	Structural members like B Pillar, reinforcements	↑↑
Aluminum Alloys	Al 6xxx, 7xxx	Closures, engine components e.g. hoods	↑↑
Magnesium Alloys	AM60B	Closures, instrument panel structure	↑
Composites	Carbon Fiber	Structural members, reinforcements, closures	↑

Source: CAR Research

THE MATERIAL QUALIFICATION PROCESS

Introduction of a new material in a vehicle is a 3-step process shown in the graphic below.

The development phase is applicable only when a new material with specific properties in mind needs to be developed. This phase involves mostly the R&D division at the material supplier and also the automaker if it is a joint development effort. Before the new developed material can be used in an automobile component, it needs to be evaluated and qualified by the OEM. The qualification phase is followed by the validation phase which involves part prototyping and performance testing. This paper focuses primarily on the material qualification step but also touches on the material development and validation process.

The process of material qualification is not standard across the industry. In fact, it differs not only between the car companies, but also is dependent on the type of material in question and the OEMs' short and long term business and technology goals. The qualification can be general (not application specific) in nature to expand the list of available materials for the product engineering department, or it can be triggered by a specific product's requirements if the available materials do not fit the role and engineers demand a new material. The product engineering and the materials engineering department, which are often involved for material qualification at an OEM, should acknowledge the following questions/issues before selecting a material and process system:

- Which vehicle component is the material for?
- How different is the material from the current materials used?
- Which part of the world and under what conditions the vehicle will be used?
- Does the OEM have a past relationship with the supplier?
- Is there an existing product in the market using the material?
- Is the supply chain for the material robust?
- Are there end-of-life considerations and regulations?
- Is compatibility with other adjoining materials in terms of joining, corrosion etc. an issue?
- Are there workforce skills and experience in working with the material?

Based on the responses from the interviews, the qualification process is generally lengthy and rigorous if:

- *The material is for a safety critical or structural application on a vehicle* – often the materials used in components which are part of the vehicle's crash energy absorption system such as A and B pillars, front bumper structure, crash rails, etc. are scrutinized more than materials used in non-critical components like interior trims, hoods, tailgates, etc.

- *The material is new and requires full analysis and characterization, plus new computation tools* – newer materials such as ultra-high strength steels, generation 3 steels, advanced aluminum and magnesium alloys, and advanced polymer composite materials, need extra analysis and specification as compared to lower grade steels. Also, the CAE tools required might be different.

- *The vehicle will be used in harsh environments* – light duty trucks and sports utility vehicles are often used in off-road harsh environments. High strength, corrosion-resistant and easily repairable materials are needed for such applications.

- *OEM-supplier relations* – the OEM may have no past business relationship with the supplier, or the supplier is new to market

- *No competitors are using the material in their vehicles* – often there is a strong reason if the material is available but not being used for an automotive application. Automakers are hesitant to be the first to try out a new material because there exist no data on its in-use failure modes.

- *There exists only a single source for the material* – most of the automakers follow just-in-time philosophy and do not carry a large inventory. Having a robust supply chain is a major factor in material qualification. A supplier may fail to provide the anticipated quantities of the material, and if it is the only supplier, the vehicle production is affected.

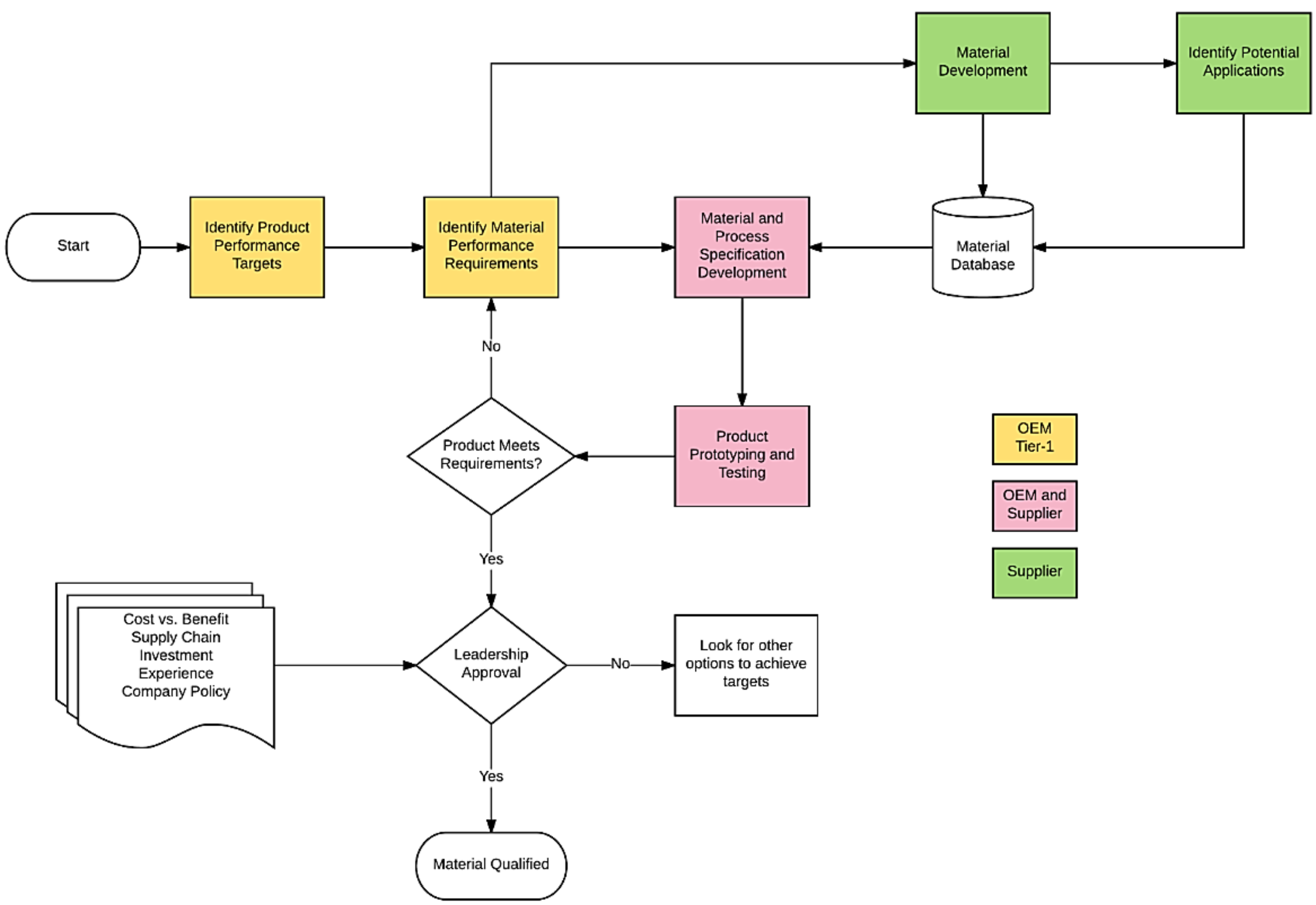
- *OEM's current capability of manufacturing equipment is limited or constrained to specific materials* – the automotive industry has been using steel to make vehicles for a very long time. Most of the manufacturing equipment like stamping dies and tools are designed to work on mild to medium grade steels. Introduction of new materials will require new manufacturing equipment, which is a big capital investment. Metals such as aluminum can use some of the same equipment used for steels but plastics and composites need a very different set of manufacturing tools.

- *Lack of experience working with the material* – every OEM has its own capabilities and internal knowledge base. Some companies have developed skill sets by using advanced materials in their low volume, high end vehicles. For example, BMW used carbon fiber extensively in the i3, i8, and 7 series; Jaguar has been using aluminum in body-in-white; and Ford developed an aluminum F150 body. These manufacturers may be more open to trying these advanced materials in new vehicles since they have gained experience in using them. If an OEM has no past experience with the material in question, the material qualification process might be more rigorous.

- *High capital investment* – The automotive industry is very cost sensitive because of intense competition and low profit margins. If the material in question requires big initial capital investment or if the cost versus benefit analysis is not favorable, then the decision makers may become hesitant in qualifying the material.

Depending on the factors above, the material qualification process could involve all or only a few of the iterative steps shown in Figure 2.

Figure 2: Generic Material Qualification Process Flowchart



Source: CAR Research

Identifying Material Performance Requirements and Material Development

Material change investigations and requests may originate from the responsible material or component release engineer, the component manufacturer, the assembly plant, or purchasing. While these persons or groups have shared objectives, each has their own particular reasons for initiating a material change. The assembly plant may initiate a material change based on assembly quality difficulties or paint and other processing difficulties. Typically, process engineers will contact either the component manufacturer or the component release engineer with these problems. The component manufacturer may be driven by piece-cost-reduction efforts or changes in tooling to reduce fixed capital costs. Typically, the suppliers work with the material providers and OEM release engineers to resolve these problems. Additional issues for the component manufacturer include workplace health, productivity (cycle time), and yield. Each of these concerns may be cause to initiate an investigation for a new material. The material supplier may try to promote the introduction of a new material with higher performance characteristics and potentially higher profit margins. Having a material approved for a new application may open up new markets for a supplier and increase production capacity utilization.[5]

If a new material needs to be developed, the target expectations for material behavior or performance should be set beforehand. This generally involves market research by discussing performance requirements through meetings between supplier and OEMs advanced engineering and material department. Often the requirements are relative to an existing material, such as more formablility, improved weldability, or added strength than a material already in use. The target can also be driven by performance of the part under specific testing conditions, this is especially true for structural components. Even if some properties of an existing material match with the requirements, the suppliers usually don't have exactly what the OEM needs, thus some development or customization to reconnect minimum-maximum performance properties is necessary before the qualification process can begin.

The results of the interviews draw attention to the fact that when OEMs are asked about their future material requirements/needs, or the development of new material grades, it is often difficult for them to be specific because they may not be completely familiar with the capabilities of a given supplier. The requirements are often relative to an existing material and may be vague. This makes the process slow and iterative since the supplier does not receive scientific targets to achieve. Suppliers begin working with clues on the OEMs expectations of the desired properties of new materials. The process can be improved by better pre-development discussions between the OEMs and the suppliers. Instead of the single supplier and OEM, these discussions may also be driven by coalition of OEM groups (such as the Auto/Steel Partnership), material supplier groups (such as CALM), and government agencies (such as the National Institute of Standard and Technology) to set material behavior goals for the industry ahead of development to facilitate open innovation. This may also promote healthy competition, leading to faster development of new materials.

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[5] Andrea, D. J., & Brown, W. R. (n.d.). *Material Selection Processes in the Automotive Industry* (Rep. No. UMTRI 93-40-5).

Material and Process Specification Development

The material qualification process begins by scientifically defining the material. This involves collection of standard material properties data. Table 1 shows some of the standard material properties for metals that should be conclusively known, although the exact requirements differ between OEMs. In order to collect these, several standard tests are performed on the material to document stress-strain curves, n-value, r-value, local formability, bendability, surface properties, microstructure and chemistry, environmental sustainability, temperature durability, etc., depending on the type of material in question.

The type of specifications and the tests required depends also on the intended function or application. Every material needs a separate set of specifications that are reflective of how the material will behave and as a measure of material quality and ability to meet the performance requirements. Plastics and composite materials may need a different set of specifications than metals because their behavior is very different under loading. Unlike metals, testing for thermal durability and flammability is a priority for plastic and composites. Table 2 provides examples of additional specifications needed for qualification of plastics. The specifications may also differ between different grades for the same type of material, for example, higher grade heat-treated steels require an additional set of specifications than traditional steels because they have microstructure dependent properties and may be more brittle than conventional grades. The brittle nature makes it important to accurately capture crack propagation properties. Thus, the advanced high strength steels need additional testing for qualification, especially the grades that are press hardened. Also, extra specifications need to be developed for computer simulation purposes, which adds time to the qualification process.

Table 1: Examples of material properties required for material qualification

Physical Properties	**Static Mechanical Properties**	**Durability and Damage Tolerance Properties**	**Environmental Effects**	**Manufacturability**	**Certification**
Density	Tensile Strength	Fatigue Strength	Temperature Humidity	Castability	Material Specs
Thermal Expansion	Compressive Strength	Notch Sensitivity	Chemical Resistance	Formability	Process Specs
Heat Capacity	Shear Strength	Crack Growth	Wear	Deformation Characteristics	Approved Supplier List
Thermal Conductivity	Bearing Strength	Toughness	Corrosion Resistance	Weldability	Repair Methods
Poisson's Ratio		Special Design Factors	Oxidation Resistance	Machinability	Safety
Tensile, Compression, Shear, Bulk Modulus				Assembly Chemical Processing	

Table 2: Examples of additional specifications required for plastics

Physical Properties	**Static Mechanical Properties**	**Durability and Damage Tolerance Properties**	**Environmental Effects**	**Manufacturability**	**Certification**
Thermal Properties Differential Scanning Calorimetry (DSC) Thermo Gravimetric Analysis (TGA) Dynamic Mechanical Analysis (DMA)	Impact Strength Heat Deflection Temperature (HDT)	Continuous Use Temperature (CUT) Creep Exposure to Automotive Fluids	Recyclability	Cycle time Mixed Material Joining	Reparability

Most of the testing to develop material specifications is done in-house at the supplier location, but the OEM may also perform some critical tests for verification. For some new materials which are not proven in the field yet, third party independent laboratory testing and certification may also be requested by the customer to increase confidence in the material behavior.

Every OEM has different requirements for material specifications or properties needed for qualification. The requirements differ between North American, European and Asian companies, but there are also differences within the North American companies. For example, NVH requirements may differ between OEMs. The unique internal requirements for material performance makes it difficult, if not impossible, to manufacture material with specifications that will suit all OEMs. Some specifications are standardized within the NA companies, especially for steels, but OEMs often add unique requirements. Specification criteria are to some extent similar for steels and aluminum within the NA region, but for plastics and polymer composites, there can be vast differences in requirements. Unlike steels which are often sold and purchased as a commodity, composites are unique to the supplying company and brand. The plastics and composites industry offer specialized products so that they can utilize the most advanced and current research in material technology. Composites are unique because their properties can be adjusted or can be developed from scratch based on the customer requirement. Since their behavior is highly chemistry dependent and they are non-isotropic, they require additional testing for development of unique specifications for product design and simulation purposes. For example, moisture absorption in a major consideration for nylons and other polymers. When the OEMs look at qualification for plastic and polymer composites, the analysis is initially based on resin or fiber chemistry. The supplier may not wish to share all the information to protect intellectual property or may insist on a non-disclosure agreement which requires legal agreements. This is a challenge in qualification of specialized, branded materials.

Developing material samples for testing requires allocation of expertise, resources, time, and money. Statistically, up to 30 coils of material (if it is a newer metal) may need to be produced to validate material property ranges. Also, new test requirements are often added to the list which requires additional infrastructure and human resources that are usually quite constrained at the supplier. Some specialized tests may require third party equipment and facilities which makes the process slow and costly. Suppliers talk to various OEMs to generate a common list of tests and procedures required for qualification. This helps them develop common specifications before the process starts, but most of this effort will need to be repeated again if the product reaches production. There can be a significant time gap between material development and actual production. Suppliers usually need to make the big initial investments for R&D and testing.

Efforts in the past have been made to standardize some specifications and testing procedures for steels to help reduce cost and increase availability. Similar efforts are recommended for new materials to standardize specifications. Trade associations and research partnerships can play a critical role in drawing consensus on standardization. For example, the Auto/Steel Partnership is taking efforts to pursue the development of common qualification and test procedures for sheet steel. The primary goal of the project is to avoid future OEM testing divergence and associated costs. A secondary goal is to help streamline the evolving product development cycle. Efforts include development of standardized, local formability testing and reviewing all related automotive and steel qualification and testing procedures.[6] In plastics, ASTM D20 is an organization for development of test methods, specifications, recommended practices, nomenclature, and definitions. To help with standardization of plastic specifications, while there is good representation of plastic suppliers, the participation of OEMs could be improved.

Identifying Potential Material Applications

This step involves brainstorming potential applications of the material in question. This may also be the first step in material qualification where the product engineers may ask the materials department to look for a material with special properties to meet product's performance and design requirements. If the potential applications identified are structural, or are critical to the vehicle's integrity and passenger's safety, then the material will be more intensely scrutinized. Collaborative multi-scale approaches for selecting the appropriate material has been developed by leading software developers (Dassault, Granta, and others). These can be used by OEMs and suppliers to virtually screen multiple materials for computational evaluation faster than through experimentation and enabling finite element analysis, deformation and crash simulation.

OEMs are looking more and more towards multi-material vehicle approaches, with the philosophy of placing the right material at the right place in their vehicles. For example, advanced steels, polymer composites and carbon fiber reinforced plastics are being used for structural components; aluminum for closures; and magnesium for seats and instrument panel beams. Collaborative cross-industry research at a pre-competitive level is not widespread, which hinders the growth of advanced materials in ground

[6] http://www.a-sp.org/about-a-sp.aspx

vehicles. Some material specific industries such as steel have formed collaborative groups to promote their material. For example, The Auto/Steel Partnership and Steel Market Development Institute (SMDI) perform research and publish potential uses of advanced grades of steels enabling process results to promote rapid implementation. Similarly, the aluminum industry relies on the Aluminum Association. The plastics and polymer composites industry came together to form the American Chemistry Council (ACC). There are a vast number of specialized, proprietary material compositions and processing techniques within the plastics and polymer composites industry – a strength that allows materials to be tailored to specific needs but also creates barriers to address major challenges collaboratively. The American Chemistry Council published a roadmap (see figure 3) which addresses industry trends to enable increased use of plastic and polymer composites. Other industries also have similar consortia where they try to promote their specific material.

Figure 3: Plastics and Polymer Composites Technology Roadmap for Automotive Markets Strategy[7]

Industry-Wide Demonstrations

1. Establish an independent, pre-competitive technology development center where OEMs and suppliers can conduct laboratory work and test concepts at small volumes while collecting standardized data
2. Develop generic cost models to demonstrate the cost and benefit of plastics and polymer composites compared to alternative materials as examples to provide mass reduction possibilities

Material Selection & Part Design

3. Define a standard package of material properties desired for automotive applications, and then test the data through simulation for a specific automotive system (e.g., engine mounts, instrument panel, cross-car beams)
4. Establish design guidelines (e.g., for wall thickness, radii) and tools for typical plastic and polymer composite structures that are intended to be used by design engineers
5. Develop models that can simulate the behavior of plastic and polymer composite materials and components during and after impact events

Manufacturing & Assembly

6. Develop a manufacturing center or consortium to advance high-speed polymer composites processing
7. Develop technically and economically viable techniques to join plastics and polymer composites to similar or dissimilar materials and study service, repair, and disassembly

Continued Materials Development

8. Support development of engineered plastics and polymer composites with improved properties (e.g., stiffness, strength, fatigue, environmental resistance, creep, energy management, temperature capability), and develop performance standards to characterize the properties for designers

Supporting Initiatives

9. Advocate for plastics and polymer composites training classes and degree programs at all major universities

Source: American Chemistry Council

[7] Plastics and Polymer Composites Technology Roadmap for Automotive Markets Strategy, American Chemistry Council, 2014

Sometimes a supplier may independently develop a material based on general market research or to fill a perceived gap in offerings. Individual suppliers or consortia of companies might research and publish literature on potential use for new materials. These publications are often used by the OEMs for reference and suppliers use them as a tool for marketing their product. For example, the European Aluminum Association (EAA) publishes updates in the Automotive Aluminum Manuals[8] as a technical reference in six major categories: applications, design, materials, products, manufacturing technologies and joining techniques. The Auto/Steel Partnership published in-depth case studies of advanced high-strength steel applications which included components like A-Pillar, Roof Rail, etc.[9] The FutureSteelVehicle (FSV) is the most recently completed automotive lightweight demonstration project from WorldAutoSteel. The FSV project included development of new AHSS grades to optimize grade and gauge reductions and improved manufacturing technologies to support the implementation of the new grades.

The Coalition for Lightweighting Materials (CALM) is a unique working group at CAR which facilitates mixed-material vehicle design by connecting diverse material suppliers to work on a project or application to demonstrate new technologies or materials. The latest CALM report titled "Mixed Materials Solutions: Alternative Materials for Door Assemblies"[10] has undertaken a co-development demonstration project focused on mixed-material solutions for a high volume vehicle door. By fostering communication and collaboration between and among heretofore competing suppliers, the project helps to demonstrate and accelerate the introduction of lightweighting technologies. Through this collaborative process, the co-development team offers a dozen integrated solutions deploying a mix of materials and technologies. Weight reduction for a surrogate door assembly used in the project reached up to 65 percent compared to the initial, mild steel-based design. Every technology and process included in the project is available and ready for deployment in the design of new vehicles.

Another challenge in identifying applications for newer materials is that the Vehicle Development Plans (VDP) are very tightly scheduled and allows only a few days to make decisions over materials to be used for the parts in question. Engineers develop alternatives and provide information; managers assess uncertainties and make decisions. After the deadline, the decisions over material are frozen and all the future steps depends on them. Thus, the decisions over material are rarely changed once they are fixed. Due to short decision period available, the managers tend to stick with the established materials which they have previous experience with unless they cannot meet their targets. At the VDP stage, it is already too late for newer materials to make place into the product. The potential material applications need to be demonstrated ahead of time. Projects such as Multi-Material Lightweight Vehicle (MMLV), a concept vehicle designed by Ford and Magna under a project funded by the U.S. Department of Energy's Vehicle

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[8] http://european-aluminium.eu/resource-hub/aluminium-automotive-manual/

[9] Advanced High-Strength Steel Applications Design and Stamping Process Guidelines, Auto/Steel Partnership, January, 2010

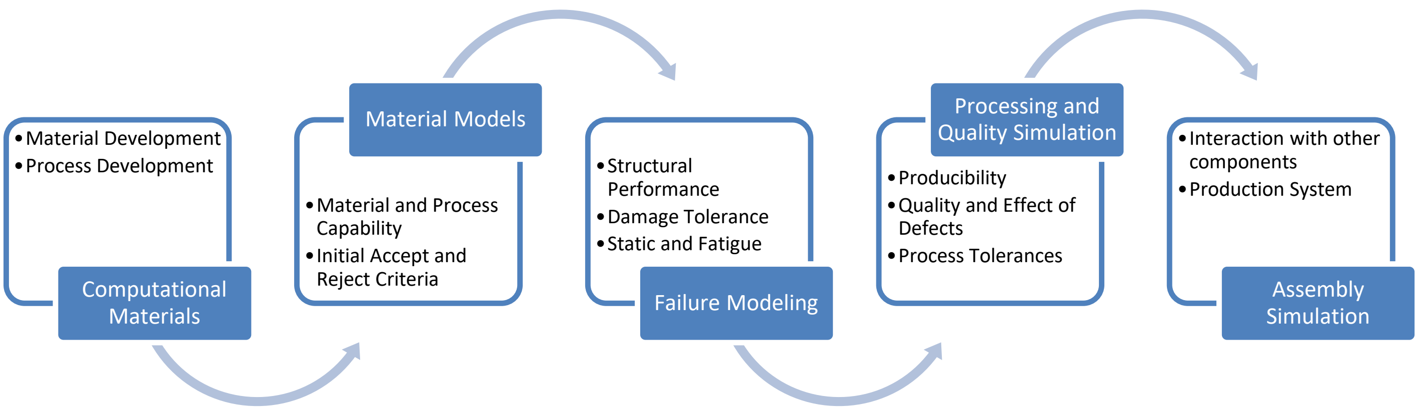
[10] Stevens, M., Modi, S., & Chess, M. (n.d.). Mixed Material Solutions: Alternative Materials for Door Assemblies, CAR, August, 2016

Technologies Office, help to better understand how lightweight materials act in real-world applications.[11] Such references can be used by the leadership at the OEMs and tier 1s during the actual decision making process.

Product Prototyping and Computational Analysis

OEMs may want to test the potential applications of the new material. The material, structures, and manufacturing can be defined and certified in digital form to meet platform requirements and/or by prototyping and physical tests. Since physical prototyping is expensive, the industry relies mostly on computation analysis and expert opinions in the initial stages. The ability to reliably predict crashworthiness, durability and noise vibration and harshness ahead of hardware builds and physical

Figure 4: Digital Certification Process



testing has a profound impact on product development cost and time. Figure 4 shows the general process for digital certification.

The auto industry lacks reliable material models needed to digitally test vehicle components made from newer lightweight material substitutes, including advanced aluminum alloys, ultra-high-strength steels and advanced polymer composites. Different material models are required for different materials. Fracture modeling and crack propagation behavior are important aspects in the qualification of high-strength materials. Experts argue that existing material models have failed to accurately predict fracture in high strength materials in the past. For plastics and polymer composites, the simulation results do not often match with the physical testing results for multiple reasons. One major reason is that plastics and composites utilize different part manufacturing processes than metals. Process and material go together for accurate prediction of part performance. The tools need to be specifically designed to model plastics

[11] Skszek, T., Conklin, J., Zaluzec, M., & Wagner, D. (2015). The multi material lightweight vehicle (MMLV) project. Warrendale, PA: SAE International.

and composites. Another issue is that the accuracy of results also depends on the human expertize of the simulation engineer. By establishing predictive capability for the development of microstructural features in relation to processing and relating this to critical property characteristics and proper workforce training, a streamlined approach to qualification is possible. The Federal government launched the Materials Genome Initiative (MGI) in 2011 to develop an infrastructure to accelerate advanced materials discovery and deployment in the United States. Goals of MGI include integrating experimentation, computation, and theory and equipping the materials community with advanced tools and techniques, and making digital data accessible. Several efforts to develop computational tools for advanced materials are being funded under this initiative. For example, the Center for Hierarchical Materials Design (CHiMaD) is a NIST-sponsored center of excellence for advanced materials research focusing on developing the next generation of computational tools, databases and experimental techniques in order to enable the accelerated design of novel materials and their integration to industry.[12] Similarly the European Commission is supporting an Integrated Computational Materials Engineering expert group (ICMEg). ICME is an approach to design products, the materials that comprise them, and their associated materials processing methods by linking materials models at multiple length scales. ICMEg aim is to bring together simulation software providers around the world, establish an open and easily accessible formulation of a global standard, significantly facilitate the exchange of data between different tools, allow for easy integration between commercial and academic approaches, and provide the pathway for life-cycle modeling of components/products.[13]

Leadership Approval

Leadership approval can be the tipping point in the process of material qualification. The OEM's decision to qualify a material for the engineering department typically lies in the hands of the materials department. Although the materials department is often the primary point of contact between the supplier and the OEM, other departments like manufacturing, advanced engineering and purchasing are involved in decision-making. Also, upper management approves the new material and the supplier(s) after considering both technical and business factors. To understand the total, material-decision-making process one must look at all the all the phases in the life of a vehicle: design, product engineering, tooling construction, production processes, surface finishing, assembly, market impact, and recycling of used scrap.[14]

Decision-making relies on factual data as well as past relationships. If the OEM has had a positive business relationship with the supplier in the past, then the relationship and trust between the individuals involved is already established. This eliminates the initial challenge that new suppliers face in getting their products noticed by the OEMs. If the supplier is new to market and has a unique or niche product lineup which has

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[12] http://chimad.northwestern.edu/

[13] http://www.icmeg.euproject.info/

[14] F. Forcucci, 'Towards PMCAs for Bodywork Parts," Automotive Technology International 1989 (1989), 77-80.

not been proven in mass-produced parts before, then the qualification process can be a lengthy and difficult one.

A robust supply chain is one of the most important criteria in OEM leadership's approval for material qualification. OEMs do not want a single source of material for the product in question; it is a big risk for their business because in case the particular supplier is no longer able to make the material, the OEM's production may be halted. For example, the 2016 earthquakes in Japan had aftershocks on the US auto industry, creating a parts shortages because of earthquake-related supply issues. Toyota had to shut down most of its factories in the country, GM and others also had to partially stop production. To manufacture high volume vehicles, the supply capacity should be adequate to meet the requirements. BMW partnered with the SGL Group and invested money to create an exclusive supply chain to meet its carbon fiber requirements for production of BMW i3, i8 and 7-series models. One of the major factors behind Ford's decision to use aluminum for its high volume F-150 light truck for weight reduction was supply chain robustness. Ford F-150 is produced in only two plants in North America for which the aluminum supply chain was developed to meet the production capacity of the light truck (more than 700,000 units sold annually). Often the material suppliers develop advanced materials independently and brand them. Even if the material is the best potential option, but if there is only one source, then the material may not be approved. The decision makers not only look at the robustness of tier 1 suppliers, but also take into account the source of the raw material. For example, source of the mineral for metals is an important consideration. In case of plastics and polymer composites, currently the supply chain is not sufficiently integrated among OEMs, suppliers, and material developers on material development, part design, and manufacturing and assembly, often because of intellectual property or other legal or business issues.[15]

The existence of global platforms is another important criterion in the decision process. There is an increasing trend among car companies to reduce the number of platforms to share engineering resources and reduce cost. According to IHS Automotive, other than Toyota and General Motors, the rest of the major global OEMs will be driving about 80 percent of their business volume on two to four platforms between now and 2021.[16] Also, the OEMs are moving towards a broader industry trend of using flexible, modular platforms that will be used in both mature and emerging markets. If the models on the platform are sold globally, the materials used should be readily available at all the production facilities across the globe without a significant cost premium. Thus, OEMs try to stay with materials that are easily available and meet the global standards. Although, there is a distinct lack of truly global standards which are used in the industry, other than the OEMs own internal standards.

Qualification may involve two known materials which are to be used together in a multi-material assembly. Compatibility in joining, corrosion and protective coating then becomes the primary concern. Decisions in such cases are based on availability of technologies that can enable the use of the material

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[15] Plastics and Polymer Composites Technology Roadmap for Automotive Markets Strategy, American Chemistry Council, 2014

[16] http://articles.sae.org/13537/

for such new applications. For example, aluminum is not welded easily, it has to be put together using adhesives and rivets. In case of mixed-material assembly, end-of-life material separation and reparability is also a concern.

Also, experiences of decision-makers, where the material may have come in the spotlight, shows up in the material approval process. Sometimes a material may pick up a negative reputation because a product failure may be traced back to material choices. This creates a fear of failure in the minds of the engineers and management, which can become a major cultural hindrance in qualifying the material or similar materials for future use.

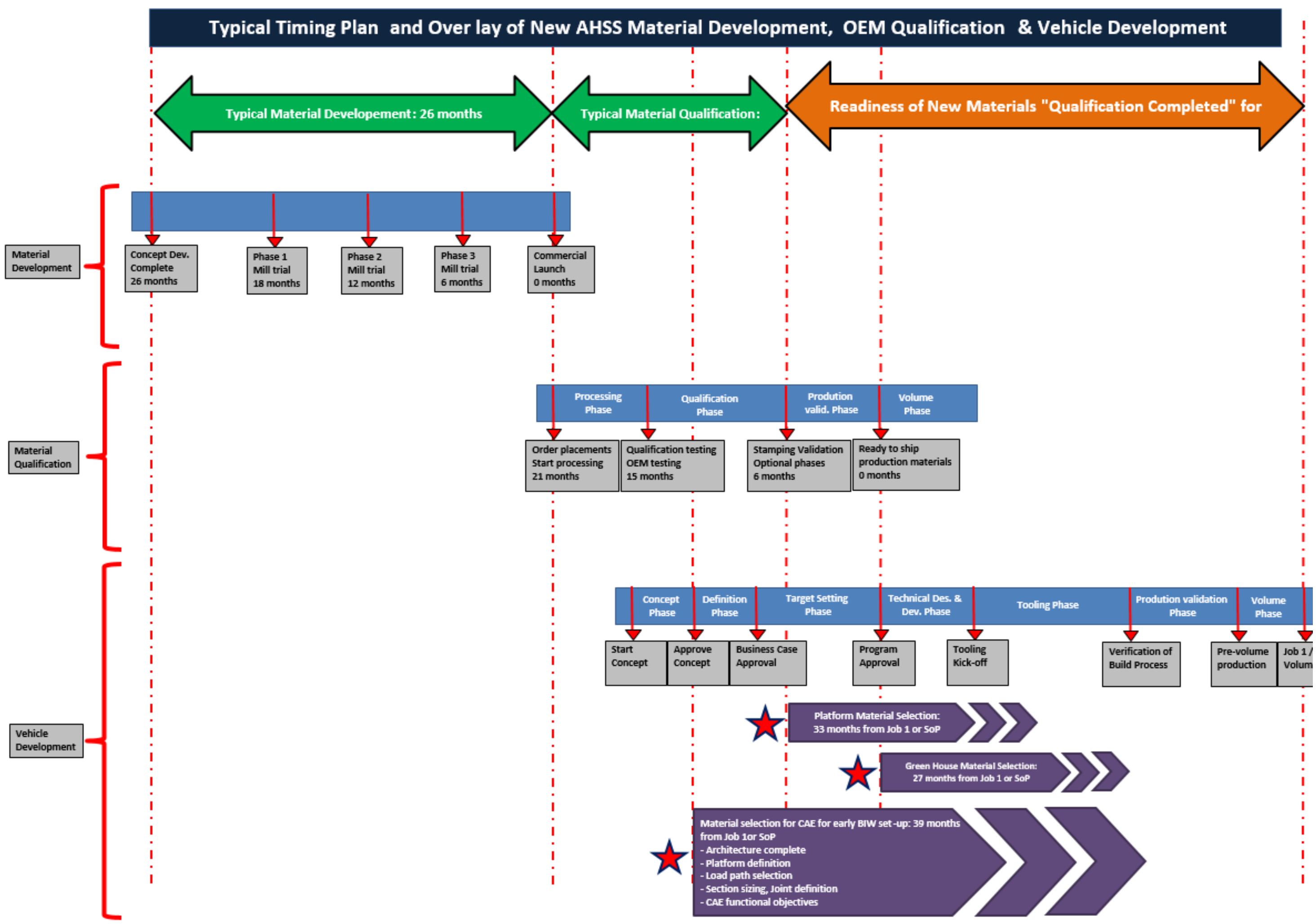
MATERIAL QUALIFICATION TIMELINE

The industry average for new material qualification for metals is around 18-20 months. For plastics and polymer composites, the qualification time is around 5-7 months because it takes less time to change their properties to match the customer requirements. Usually material qualification and part specific testing occurs with overlap and over several iterations. The data behind these averages assumes that the application is purely material substitution. This time-period does not include the lengthy material development process. If the design needs to be changed, then the qualification time can take several more months. To get real benefit out of plastics and composites, the part needs to be redesigned. Plastics and composites offer several advantages like part consolidation which provides lightweighting. The time for qualification is more than average for materials which have never being used in an automotive application before.

For products that require major process change on the OEM side – the qualification timing can be significantly different than materials that require minor process change or doesn't affect the cycle times. Process material changes (such as for metal pretreatment and adhesives/sealant applications to body-in-white structures) may demand significant infrastructure/cycle time change investment by the OEM, and therefore require more time for approval and implementation (as much as 3 to 4 times as long as part qualification). This is, in essence, one of the major issues for body structure material approvals and changes, requiring up to 15-year time allowance between introduction to commercial use of new materials. For example, paint shops are a very high investment asset in an assembly plant; the decisions over material change that requires process changes in the paint shop takes time and requires consensus of every department at the OEMs.

Figure 5 shows a typical timing plan for development and qualification of advanced high strength steel. The material development process is usually 26 months long, followed by the qualification phase which is 18-21 months long depending on the type of material and its history in the automotive industry. The material is usually qualified for use around 33 months prior to start of production or job one.

Figure 5: Material Qualification v/s Vehicle Development Timeline



Source: U.S. Steel

BENCHMARKING WITH THE AEROSPACE INDUSTRY

Aerospace structural materials require a rigorous, expensive, and time-consuming qualification procedure prior to their implementation onto an air vehicle system. The data requirements necessary for material and process qualification are extensive and often require millions of dollars and multiple years to complete. Furthermore, these qualification data can become obsolete for even minor changes to the processing route. The traditional approach to qualifying materials leads individual companies to use "customized" qualification programs, leading to detailed and expensive procedures for each company. Costs increased further as other procedures were established for structural testing, manufacturing control and repair. As a result, most programs were limited to using materials previously qualified for other programs, which led to using older, outdated material and not taking advantage of the latest technology and material advances in the industry.[17]

The FAA released, "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems," known as the AGATE methodology for short. This document presents the detailed qualification plan used to generate statistically-based design allowables for composites at the coupon level. The allowables give end users a statistical confidence that the material properties will be at least as good as the minimum allowables.[18] With the creation of AGATE, the AGATE Shared Database Process was formed. The shared databases allowed a manufacturer to select a pre-approved composite material system to fabricate parts through a smaller subset of testing for a specific application (known as equivalency). AGATE was able to reduce the time required for certification of new composite materials by a factor of four and the cost of certification by a factor of 10.[19] Although the AGATE program ended in 2001, the composite qualification methodology remains an active standard today under the National Center for Advanced Material Performance (NCAMP).

Benefit to aircraft manufacturers: Instead of qualifying an entire material system, manufacturers can pull a system from the NCAMP database, prove equivalency and gain FAA certification in a quicker and cheaper manner than a typical qualification approach.

Benefit to material suppliers: Material suppliers can work with NCAMP to qualify material systems without having to be linked to an ongoing aircraft certification program. This allows the material supplier to get its material out into the market via a public forum with generated allowables and FAA certification.

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[17] http://www.niar.wichita.edu/coe/ncamp_history.asp

[18] http://www.compositesworld.com/articles/agate-methodology-proves-its-worth

[19] http://www.niar.wichita.edu/coe/ncamp_history.asp

Equivalency testing allows smaller material producers to qualify their product relatively quickly and affordably and thus enables a larger supply chain.[20] Although the aerospace industry is very different than the automotive industry, a similar approach to standardize the qualification process may reduce time and cost.

OEM PHILOSOPHY AND RISK MANAGEMENT

Car companies can only deal with incremental improvements in material technology. Revolutionary new materials are not anticipated by the car industry, rather the OEMs rely on evolution of the current material technology. There are several risks involved with revolutionary materials:

1. **Risk of part failure and vehicle recall**: A product recall is a request to return a product after the discovery of safety issues or product defects that might endanger the consumer or put the maker/seller at risk of legal action. The recall is an effort to limit ruination of the corporate image and limit liability for corporate negligence, which can cause significant legal costs. Several automakers in the past have invested billions of dollars to recall defect vehicles. The experience has forced the industry to implement stringent material qualification procedures to safeguard against future damages.

2. **Failing supply chain**: Due to unforeseen circumstances the material supply chain can fail leading to delays in vehicle production which is a significant financial loss for an automotive company. For this reason, OEMs make sure that robustness of the supply chain is a priority when qualifying a new material. For example, China effectively controls the global magnesium market, responsible for anywhere from 70 to 80 percent of production. Given the slowdown in China's economic growth rate, which many expect to continue, excess supply of magnesium compounds (magnesia) is a looming factor to weigh against any capacity expansion. [21]

3. **End-of-life recycling and public health**: Recyclability is a very important material property for material qualification. With the gamut of environmental laws and for ethical reasons the OEMs need to be sure that the material in not detrimental to the environment or general public health. For example, the use of lead is prohibited because of health concerns.

4. **Cost versus benefit**: A change in material may improve the performance of the product but the cost may far exceed the real life benefits. The car companies are constrained by cost and hence are forced to make practical decisions on material choices to make sure that the cost of the vehicle does not increase by an unprecedented amount. For example, carbon fiber composite materials

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[20] Brice, Craig A., "Unintended Consequences: How Qualification Constrains Innovation," National Aeronautics and Space Administration

[21] Berry, C., A Closer Look at Magnesium, zimtu research, July 2015

provide strength to the vehicle's structure while reducing weight by almost 50% compared to mild steels but are very expensive. Carbon fiber for automotive costs $10 to $12 a pound, compared to less than a dollar for steel. To see more widespread adoption, carbon fiber needs to get down to about $5 or $6 a pound.[22] Currently, carbon fiber composites are only used in high end luxury and performance vehicles where customers expect the high end technology and are willing to pay for it.

5. **Customer expectation**: market forces often play a major role in material choices, especially for interior trim materials. For example, if the majority of customers prefer leather interiors, an OEM may be hesitant to try out new materials even if the materials are better and costs less.

It is also important to acknowledge differences between European and North American OEM's material qualification philosophy. The interviews steer to the fact that European manufacturers generally qualify the part, not the material. They are willing to work more closely with their suppliers than their North American counterparts. This is a subtle but important distinction because a one-to-one close relationship with the supplier to make the final product work can help to accelerate the pace of material technology in the fleet.

SUMMARY AND RECOMMENDATIONS

Material qualification is a process which takes place between the OEM and the material supplier before a material can be used in an existing product or a new vehicle application. The steps involved in the process are mostly iterative. These steps are: discussing performance requirements with the OEMs prior to development, developing the material, validating the performance of the material through qualification testing, reviewing the qualification results with the end customer and obtaining official customer approval. The general timeframe for qualification is around 18-20 months for metals and 5-7 months for plastics and polymer composites in the automotive industry. Although it may take 3-5 years from material development to its introduction into the vehicle fleets. Several issues and opportunities are identified in this whitepaper for faster introduction of new materials. CAR would like to make the following recommendations:

1. **Collaborative Efforts and Open Innovation Challenges**
    - Faster introduction of new materials requires collaborative efforts. CAR recommends standardization of testing requirements based on material type across the industry for a faster, streamlined and cost-effective material qualification process. Having a centralized source for material properties and performance data could improve communication among material developers, tiers and OEMs and optimize material selection.

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[22] Bregar, B., Price keeping carbon fiber from mass adoption, August 2014 http://www.plasticsnews.com/article/20140805/NEWS/140809971/price-keeping-carbon-fiber-from-mass-adoption

- Creation of shared material properties database will allow engineers to select a pre-approved material to fabricate parts through a smaller subset of testing for a specific application. These databases can be supplemented with generic cost models.
- Suppliers and OEMs should consider cost-sharing for development and qualification of new materials. This will enable small suppliers to move their products quickly to the market and give the OEMs an upper hand in the material development process. Increased coordination is essential to help accelerate innovation.
- Breaking the cultural barriers in introduction of new materials can be tough. Collaborative, pre-competitive research, through consortia of materials supplier and OEMs, will facilitate product prototyping and testing to showcase potential applications of the new material. This will increase OEM confidence in new materials and new material applications.
- Open innovation challenges by the OEMs will encourage healthy competition between the suppliers and can lead to innovative and cost-effective products.

2. Better Communication and Workforce Training

- Since material qualification involves every department at an OEM, it is recommended to have a detailed and transparent communication process especially between the engineering, manufacturing, materials and purchasing department.
- There is a need to educate engineers and overall workforce to be capable of applying and or developing material models and applications. Continuous education programs and workshops on new material technologies improve general understanding and can boost enthusiasm on using new materials for engineering applications.
- Industry and government funded projects that showcase potential applications of newer materials at a precompetitive level can be used as references by engineers when looking for alternate materials to achieve performance, cost and weight targets.

3. Reliable Simulation Tools

- Much of the design and testing of materials is currently performed through time-consuming and repetitive experiment and characterization loops. Some of these experiments could potentially be performed virtually with powerful and accurate computational tools, but that level of accuracy in such simulations does not yet exist.
- Accuracy in predicting the material behavior through computer simulation is the key for a cost-effective qualification process. The industry should devote resources for the development of scalable, multi-phenomenon modeling tools that can be integrated with design analysis, plus testing protocols that incorporate a true understanding of material behavior and failure modes such as corrosion, fatigue, creep, crack propagation, etc.

4. **Advanced Forming and Joining Technologies**
    - Advancement in forming technologies is a key enabler that promotes new materials in automotive components. Due to high production volumes, the auto industry demands short cycle times (less than 1 minute per part). A stamping die can cold stamp 15-17 parts per minute compared to only 2-3 hot stamped parts per minute (assuming a similar sized part). Polymer composites and plastics have longer cycle times than metals. There is a need for collaborative industry effort to research and push innovative, advanced forming technologies such as additive manufacturing to reduce cycle times for enabling faster introduction of new materials in mass production.
    - As the industry moves towards mixed-material vehicles, joining technologies have become a major deciding factor in material selection. Need for joining technologies that enable joining between conventional steel grades, advanced steels, aluminum, magnesium, and composites has increased. The R&D efforts should equally be focused towards development of new mixed-material welding and mechanical joining technologies.
    - Also low-cost, robust, easy-to-use, and non-destructive damage detection techniques need to be developed for newer materials especially plastics and polymer composites.

5. **Harmonization of OEM standards for material qualifications**
    - A robust international supply chain is a major deciding factor in the material qualification process for globally-produced vehicles. Automakers are working towards modular platforms which will increase part sharing between vehicles. Harmonization of specifications required for qualifications across the automotive industry will help in establishing supply chains for new materials at a much faster rate and reduce the material qualification time and cost.
    - Consistency in material grades and properties across suppliers will boost the supply chain robustness globally and increase OEMs confidence in new materials.

FUTURE WORK

While this whitepaper covers the general process of material qualification in the automotive industry, many opportunities for an in depth research remain. CAR recommends the following topics for future work:

1. Compare technical specifications of the same material from different suppliers and between OEMs. Develop representative case studies identifying factors that contributed to the success, failure and timing of qualification of the material or process in question.
2. A study to document differences in the qualification process for recycled materials compared to virgin materials.
3. Qualification process for new products versus remanufactured products.
4. Develop a design guide for new materials such as magnesium and polymer composites.