WHITE PAPER

CARBON COMPOSITES ARE BECOMING COMPETITIVE AND COST EFFECTIVE

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Abstract

Carbon Fiber Reinforced Composites are widely used in multiple industries due to its high performance although the cost is higher compared to metals. However, recent advances in composites are driving carbon composites to be more competitive and cost effective. The reduction of defects and cycle time realized by the introduction of high-end processes is accelerating this pace further. New technological developments in fiber reinforcements, resin systems, and production concepts are continuing to drive the future deployment. This paper presents a perspective on how carbon composites are becoming more competitive and cost effective across industries. The influence of various advanced technologies in reducing the cost of carbon composites is also presented.

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1. Introduction

Composites have been widely used across industries like aerospace, wind energy, automotive, industrial, marine, oil and gas. Advanced carbon fiber composites are comparatively more expensive than metals. The choice of composites is a tradeoff between cost and performance. As a result, carbon composites have made their impact in high performance vehicles, such as, jet fighters, spacecraft, racing cars, racing yachts and exotic sports cars. The global composites materials market is about $28Bn in 2014 and is growing at 15-20% per year. This market size will further grow provided the cost of composites is reduced. The cost considered is primarily the composite manufacturing cost. However, for correct assessment entire life cycle cost need to be considered including maintenance and operation. Composites provide a cost benefit particularly in respect of operation and maintenance which form a sizable percentage of direct operating cost.

A typical cost comparison between various materials is shown in Figure 1 and Figure 2 presents the worldwide market estimates for carbon fiber. Although, the cost of carbon fibers is high, the market for carbon fiber in non-aerospace structures is increasing at a rapid rate as shown in Figure 3.

Cost of the product is the major factor prohibiting the wide spread use of carbon composites in industry. The following factors contribute to reduction of cost

- Reduction in cost of carbon fiber
- Availability of high performance resins meeting production automation requirements
- Cost effective product forms
- Cost effective production methods and automation with repeatable high quality
- Availability of relevant design and environment data on selected composite systems
- High-volume processing

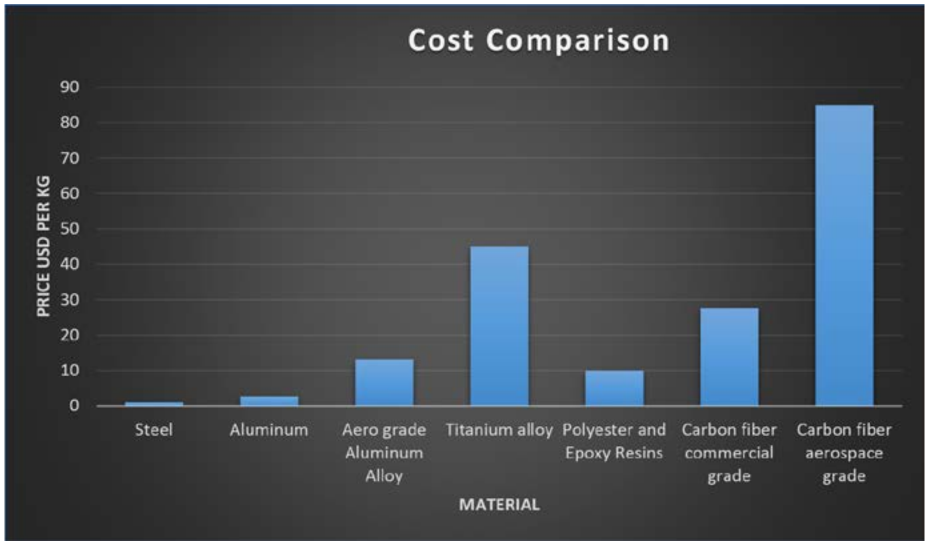


Figure 1. Cost Comparison of Materials

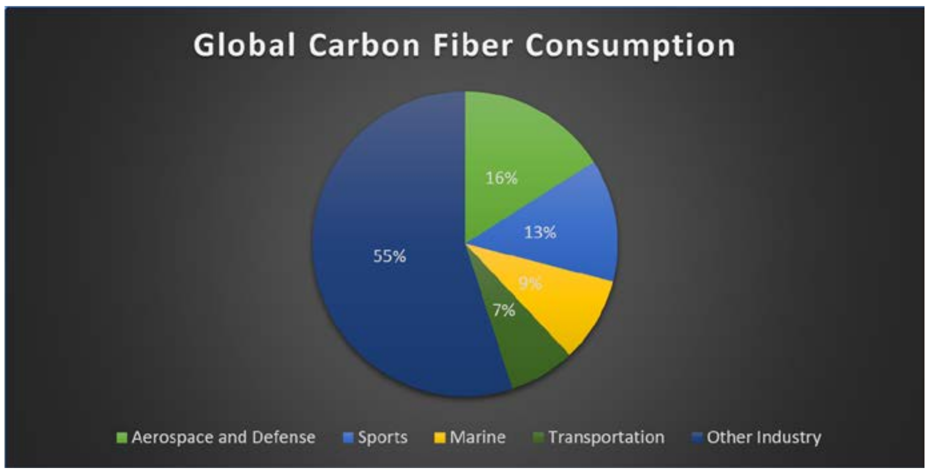


Figure 2. Global Consumption Carbon Fiber (2012)

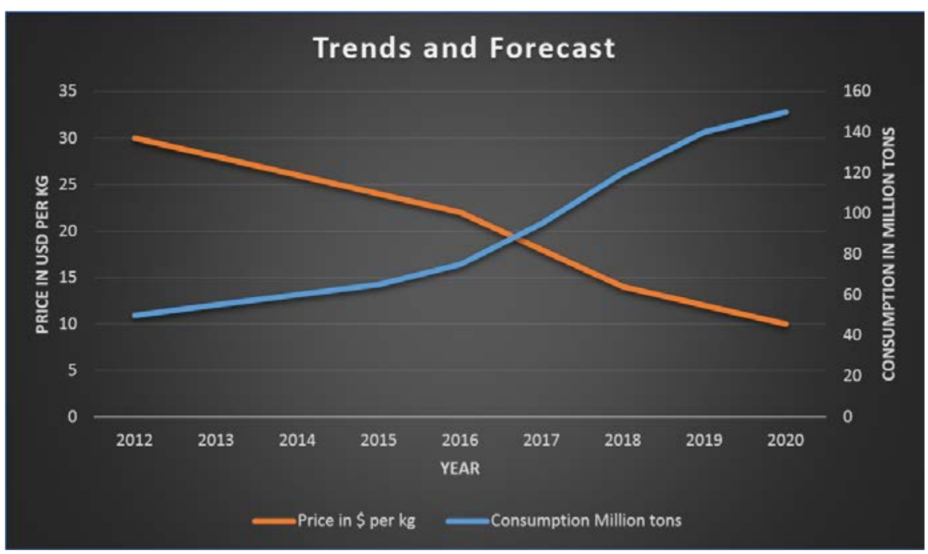


Figure 3. Trends and Forecast of Carbon fiber

2. Recent Advancements in Polymer Matrix Composites

The effort to produce economically attractive composite components has resulted in several invetive manufacturing techniques. It is obvious that improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort of key cost drivers as shown in the figure 4 for composites to become competitive with metals.

Raw Materials

Main raw materials of carbon composites are polymeric resins and carbon fibers. Cost of carbon fiber is directly related to the cost and yield of precursor from which it is obtained and cost of conversion. At present carbon fiber is Polyacrylonitrile (PAN) based and its average cost of non-aerospace grade is around $21.5/kg, with a conversion efficiency of only 50%.

The following advances are taking place to reduce the cost of carbon fiber:

- Development of low cost and high yield precursors for manufacture of commercial (heavy-tow) carbon fibers which will significantly reduce the carbon fiber cost. Industrial grade fibers are expected to be available at $13.8/kg by 2017. Figure 3 shows how the cost of carbon fiber is going to get reduced in future, till the year 2020, due to some of these advances in raw materials.
- Chopped carbon fiber/epoxy prepregs in Sheet Molding Compound (SMC) form for structural applications with processing times in minutes with 3-D molding capability that results in dimensionally controlled surfaces on both sides.
- Development of highly moldable fast cycle prepregs, uni-directionally arrayed chopped strand prepregs
- Development of highly reactive resins to reduce cycle time
- Combining fibers to create hybrids and weaving forms, re-use of waste fibers by combining and consolidating dry fibers into a mat
- Development in preform technology: multi-ply curved complex preforms such as skin-stringer / frame intersections.

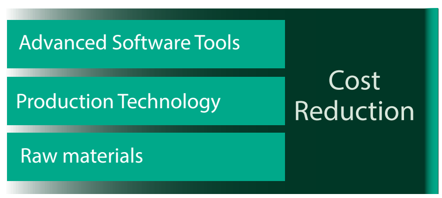


Figure 4. Key drivers for Cost reduction

Production Technologies

Many advanced production technologies are in good state of development. These have potential to reduce the manufacturing and assembly costs while capable of meeting the production volumes of specific industries. Some of them are:

- Fast cycle manufacturing techniques
- Lay-up automation and automation of labour intensive activities
  - Flexible automated composite laying processes
  - Textile processes like braiding (3-D) and preform making,
  - Forming processes
- Out of autoclave processes like resin transfer molding and resin infusion technology
- Utilization of Fluid based pressure/ heating/cooling systems
- High speed compression molding
- High pressure molding process - method of forging net shaped parts from prepreg bundles similar to metal forging.
- Rapid cure resin technology combined with RTM for fabrics curing in 10 minutes.

Advanced Software Tools for Composite Product Development

Many advanced composite software tools and utilities are now available to automate many engineering processes and to reduce design cycle time. These tools identify feasibility of manufacturing and associated issues upfront during design stage. These advanced software tools are helping to perform many engineering activities concurrently while reducing the design cycle time and engineering cost. Few of these tools include:

- Advanced design, analysis and manufacturing simulation software tools and utilities
- Knowledge Based Engineering Tools
- Design for part integration and co-cure methods
- Design integrated virtual manufacturing software systems
- Cost modeling software.

3. Industry Specific Advances in Carbon Composites

Aerospace Industry

Recent advances in aerospace structure are:

- Production of carbon fibers from Textile PAN and / or melt spun PAN likely (cost reduction by 15% to 20%)
- Dry composite preforms, woven structural braided reinforcements, complex textile based architecture associated with out- of- auto clave curing such as RTM/Resin infusion and e-beam curing
- Availability of high performance fast curing resins to meet the out-of-autoclave production processes.
- Automated Dry Material Placement (ADMP) – A newer approach to cut and place ply patterns in one operation eliminating pick up and placement approach.
- CNC controlled contour tape laying/ fiber placement machines with high deposition rates
- Manufacture of large parts through Vacuum-Assisted Process (VAP) and combined infusion of the different parts (skin and stringers), avoiding thousands of rivets and secondary operations.
- On-line quality control during manufacturing process
- Designing with heavy tows of uni-directional materials without compromising properties.
- Custom built dry fiber tapes with suitable binders, designed to be used on current AFP machines to create dry Preforms
- Development in Preforms using many passes of narrow bands of dry tape that are consolidated as it is placed

Automotive Industry

Recent advances in different areas of composites in automotive industry can be summarized into

Raw material:

- Technological advances in the area of low-cost fiber precursors such as, cheaper polymers, inexpensive textiles, low-quality plant fibers or renewable natural fibers to meet auto requirements in terms of properties.
- Novel carbonization techniques to produce useful, uniform fiber properties at low cost

Materials and forms:

- Multi-material system and Hybrids- carbon and glass
- Carbon /Epoxy SMCs
- New and faster curing resins
- Combination of material forms like chopped fibers with continuous fibers tailored to meet the requirement
- Stronger and durable adhesives

Design:

- Advances in CAE
- Change in mindset of designers
- Better integration methods with metals

Rapid economic fabrication processes capable of achieving high volume cost effective structures:

- High speed Compression Molding
- Compression molding of pre-pregs
- High speed resin transfer molding
- Resin spray transfer molding
- Reactive injection molding

Joining -fastening and bonding

- Design criteria and design methodologies
- Tailoring of adhesives and mechanical fasteners to suit Polymer Matrix Composites (PMCs)

Marine Industry

Carbon composites are considered in selected areas of marine industry in order to achieve high performance with least weight. Focused efforts are being pursued in the following areas:

- Generation of design and process data comparable to design data sheets used for steel construction
- Development of material system and designs
    - capable of functioning in hot -wet environments
    - improved fire performance characteristics
    - good damage resistance
- Total integration of technologies
- Effective NDT techniques
- Cost effective and robust production methods
- Low cost hull mould concepts in large sized hulls (>100 meters long)
- Integrated approach in design, analysis, testing, fabrication and assembly techniques.

Oil and Gas Industry

Carbon fiber Composites are recognized as an enabling technology in deep-water and ultra-deep-water (1500m - 3000m) drilling scenarios. Many developments in areas of design, manufacturing, NDT have taken place. Some of the recent advances are

- A number of standards for design, manufacture and testing, installation and maintenance were issued by European committee of standardization
- Cost effective routes for manufacture of load bearing composites (main vertical and deck elements).
- Alternate designs, for example, in the deck design, instead of sandwich construction a linked assembly of pultruded cellular elements construction to achieve the necessary degree of stiffness
- Developments in low cost manufacturing processes, like, pultrusion of deep box beam section with fibers in different orientations.
- Development of resin infusion moulding processes for very large components with high quality
- Reduction in carbon fiber costs using cheaper precursors and better conversion technologies

Rail Industry

In order to meet the demands of high speed rail industry prototype vehicles are built using carbon composites. Recent advances in this area include:

- Standardization of Fire safety regulations and issuance of harmonized standards for Fire, Smoke and Toxicity (FST) requirements
    - Techniques for design, simulation and modeling of fire response
    - Universal composite material system to meet stringent FST requirements
- Reduction in cycle time for development and validation of non-linear FE models for composites.
- Familiarization of engineers with composites
- Cost effective manufacturing techniques for:
    - Industrial reproducibility at cost levels comparable to steel
    - Producing pre-equipped subassemblies that can be assembled quickly to form a coach
- Generation of material and design standards
- Generation of Approved performance requirements

Wind Energy

Turbines blades are increasingly large to be cost effective which necessitates the use of carbon fibers. Recent advances include development of an integrated approach, combining processes, and material and design inventions. The areas of advances include:

- Multi-axial, multilayered matte/wove/UD reinforcements
- Advanced pre-pregs to produce thick sections of good quality eliminating the need for compaction
- Development of new core materials that are
- Pre-preg compatible
- Suitable for resin infusion with low resin absorption characteristics
- Higher thermal stability
- Epoxy resin reinforced with carbon nanotubes resulting in half the weight of fiber glass blade
- Special thermoplastic coatings with enhanced durability
- Thermoplastic composite materials and processes
- Application of automated technologies to shorten cycle times, increase precision and repeatability
- Automated Tape Layup (ATL) or Automated Fiber Placement (AFP) processes
- Sophisticated measurement, inspection, testing and quality assurance tools

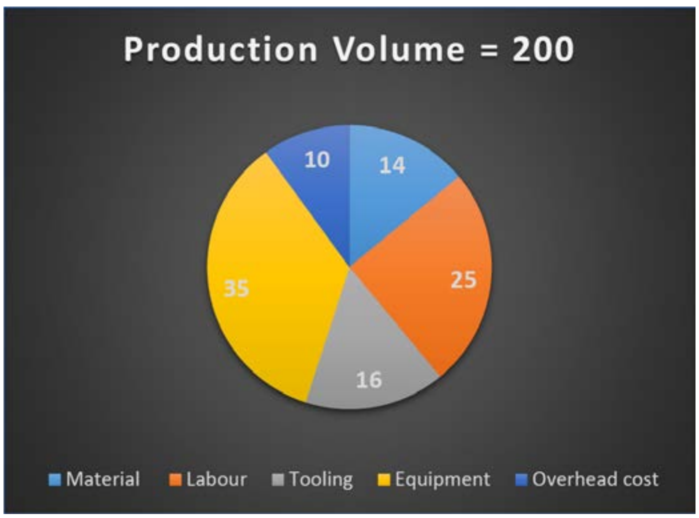
A summary of the key parameters which will influence the cost of composites in future across industries is shown in Table 1.

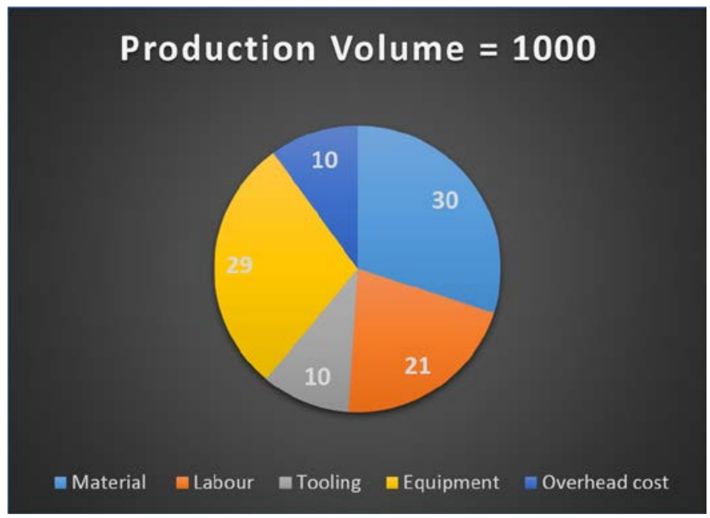
	Material	Product forms	Processing techniques	Design methods	Others
Aerospace	• Fast curing resins • Carbon fiber from textile PAN / melt spun PAN	• Automation-tape and dry fiber placement • Out of autoclave processes	• Dry preforms 2D/3D	• Use of heavy tows of UD	• On-line quality control
Automotive	• Low cost carbon fibers • Fast curing resins • Carbon / Epoxy-SMCs • Strong /durable adhesives	• High volume production • Compression molding of prepregs • Out-of-autoclave processes-high speed RTM, Reactive RTM • Automation in adhesive bonding	• Combination of chopped / continuous multi material systems	• Advancements in CAE • Better integration methods with metals	
Rail industry	• Universal composite material system. to meet Fire Smoke Toxicity (FST) requirements • Low cost fire retardant resins	• Low cost reproducible production methods at cost levels comparable to steel Methods to produce pre-equipped subassemblies that can be assembled quickly to form a coach	• Multi material and braided / woven hybrid systems	• Efficient Design simulation and modeling of fire response solutions • Material and design standards	• Standardization of Fire safety regulations
Wind energy	• Low cost fibers • Advanced prepregs to reduce production steps • Core material compatible with new resins/ prepregs • Durable coatings	• Automation-tape and dry fiber placement • Automated processes to ensure short cycle times with precision and quality	• Dry preforms 2D/3D	• PLM based integrated design methodology • Durable coatings	• Automation in inspection / Quality Assurance • Durable coatings
Oil and gas	• Cost effective high temperature / pressure resin systems • Low cost fibers	• Low cost manufacturing processes- pultrusion, resin infusion moulding		• Development of efficient designs • Design data sheets	• Regulatory requirements standardization
Marine	• Low cost fibers • High performance resins to meet harsh environment • High performance coatings	• Improved production methods • Low cost molding of large sized hulls		• Generation of design / process data sheets • Development of damage resistant design methods	• Effective NDT techniques

Table 1. Cost Reduction Parameters Industry Wise

4. Cost Analysis

The manufacturing cost of a composite product is highly dependent on manufacturing process. For example, a stiffened panel can be manufactured by autoclave process, resin transfer molding or compression molding. The major cost drivers are raw material, tooling, labour and equipment. Costs of these vary with the chosen process of manufacture and on volume of production. Figure 5 gives cost of the above parameters in percentage of total cost for a typical hand layup process for aerospace parts and various production volumes.





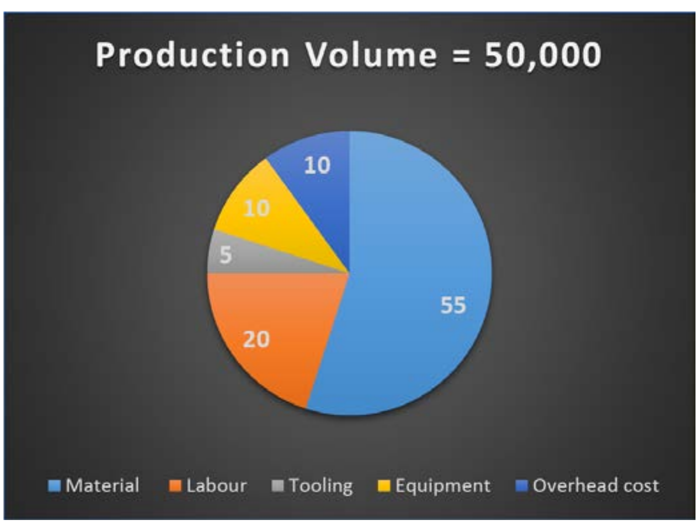


Figure 5. Influence of Production Volume on Various Cost Line Items

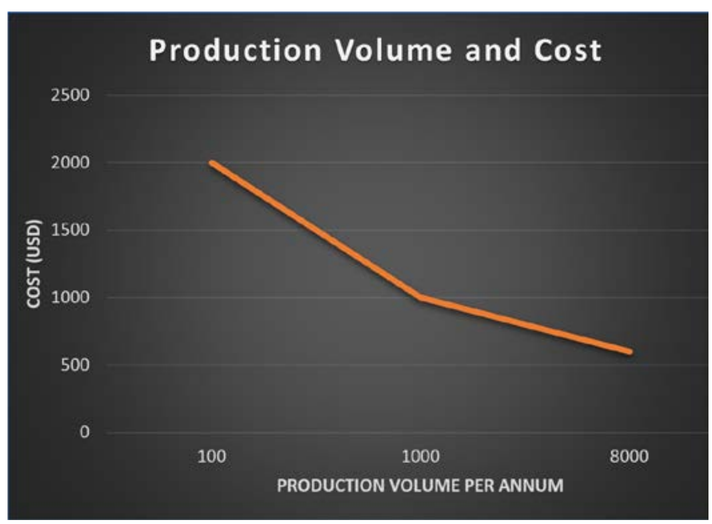


Figure 6. Influence of Production Volume on Overall Cost

All these technologies are in advanced stage and are expected to be production ready in few years from now. These are likely to reduce the material cost by 15% to 30% and the manufacturing cost by another 15% to 20%. Considering these, a cost estimate in the current year and in 2020 is made for a medium sized structural carbon/epoxy component with same mechanical performance as shown in shown Figure 7.

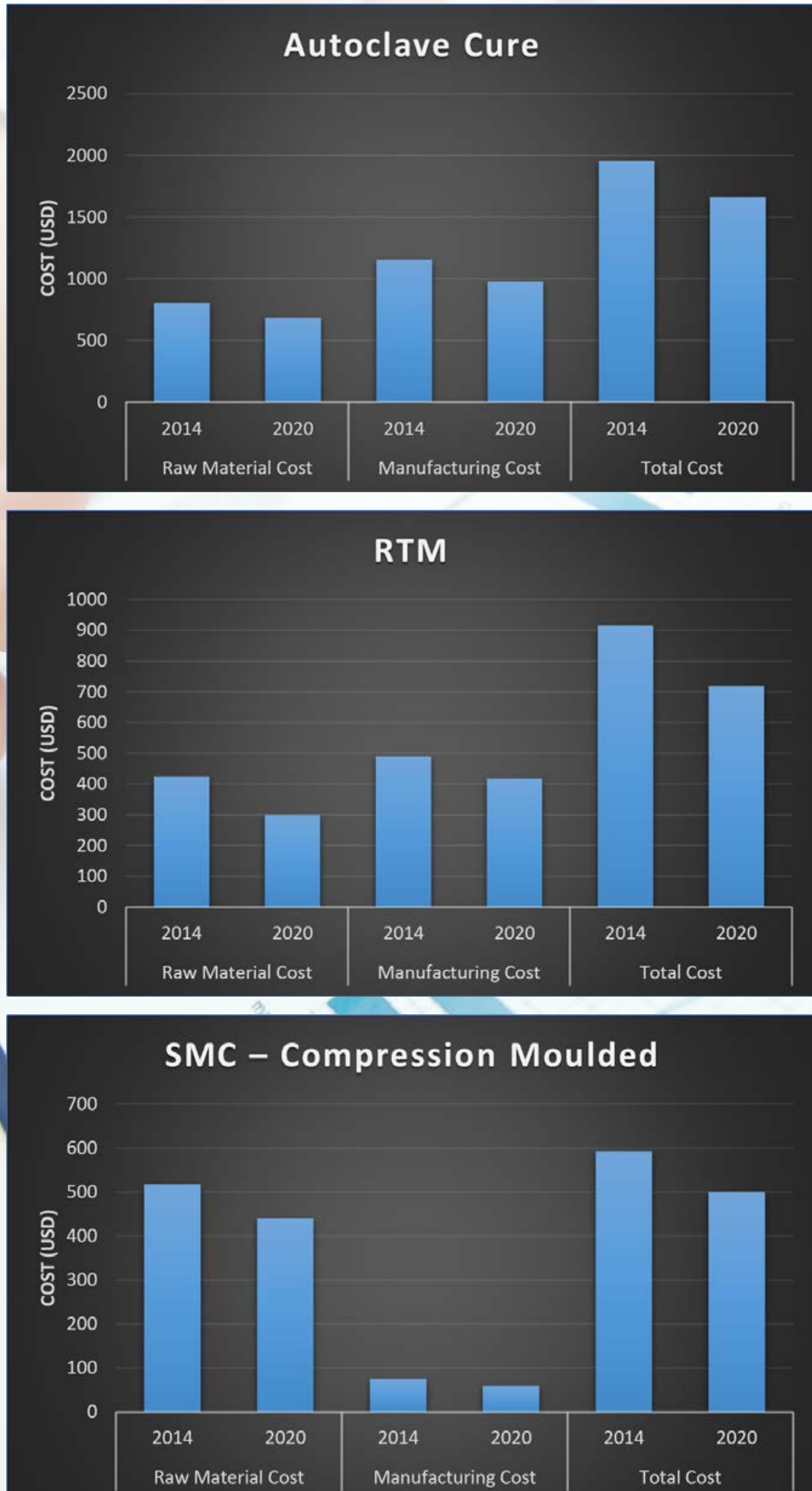


Figure 7. Cost Estimate in 2014 and 2020 of a medium size Carbon Composite Component

Conclusions

Carbon fiber reinforced composites (CFC) are becoming competitive and cost effective compared to metals. At the current rates, CFC components are costlier compared to metal components. Many advances in raw materials, manufacturing technologies, assembly techniques are influencing directly the cost of composites design & development. These advanced technologies will help reducing the cost of composites substantially which will spur the demand for composites exponentially in coming years. Composites design, analysis, manufacturing tools will help in reducing the engineering cycle time, reduce the costs and improve the quality while maintaining repeatability of parts being manufactured. This paper presents briefly various advances in raw materials, manufacturing processes and software tools which will eventually drive down the cost per kg of CFC in industry sectors such as, aerospace, automotive, marine, railway and oil and natural gas.

Acknowledgements

Thanks are due to Mr. Thirunavukkarasu K.S. for the timely help provided in preparing this document. The authors would like to thank Devaraja Holla V. for the detailed review and valuable inputs to improve the document. The authors also would like to thank senior management of engineering services practice of Infosys Mr. Srinivasa Rao P, Mr. Manohar A. and Mr. Sudip Singh for their continuous support and encouragement.

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