Using smart materials to solve new challenges in the automotive industry

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ABSTRACT

Ford has an extensive history of developing and utilizing smart and innovative materials in its vehicles. In this paper, we present new challenges the automotive industry is facing and explore how intelligent uses of smart materials can help provide solutions. We explore which vehicle attributes may provide most advantageous for the use smart materials, and discuss how smart material have had technical challenges that limit their use. We also look at how smart materials such as gecko inspired adhesion is providing opportunities during the vehicle assembly process by improving manufacturing quality, environmental sustainability, and worker safety.

An emerging area for deployment of smart materials may involve autonomous vehicles and mobility solutions, where customer expectations are migrating toward a seamless and adaptive experience leading to new expectations for an enhanced journey. Another area where smart materials are influencing change is interior and exterior design including smart textiles, photochromatic dyes, and thermochromatic materials. The key to advancing smart materials in automotive industry is to capitalize on the smaller niche applications where there will be an advantage over traditional methods.

Ford has an extensive history of developing and utilizing smart and innovative materials. Magnetorheological fluids, thermoelectric materials, piezoelectric actuators, and shape memory alloys are all in production. In this paper we present new challenges the automotive industry is facing and explore how intelligent uses of smart materials can help provide solutions. We explore which vehicle attributes may provide most advantageous for the use smart materials, and discuss how smart materials have had technical challenges that limit their use. An emerging area for deployment of smart materials may involve autonomous vehicles and mobility solutions, where customer expectations may require a seamless and adaptive experience for users having various expectations.

Keywords: Automotive, Industry, shape memory alloys, Magnetorheological fluids, thermoelectric materials, piezoelectric actuators

1. INTRODUCTION

1.1 Ford Innovations

Ford Motor Company has a long history of improving mobility. When the Ford was just a startup in 1903 Henry Ford already had 10 years of experience with gasoline engines. Ford introduced the affordable and durable Model-T only five years later in 1908 when the US had approximately 18,000 miles of paved roads. At the time, most of the automobiles were for the few that could afford the luxurious new form of transportation. It took another five years of manufacturing the Model-T before Ford introduced the integrated, moving assembly line for automotive production

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(Figure 1). Prior to this innovation workers manufactured the Model-T and all other automobiles in an “assembled car” method by groups of two or three men working on each vehicle from made-to-order components. The assembly line took several years to implement starting from basic techniques of incremental mass production with a smaller scale.[1,2]

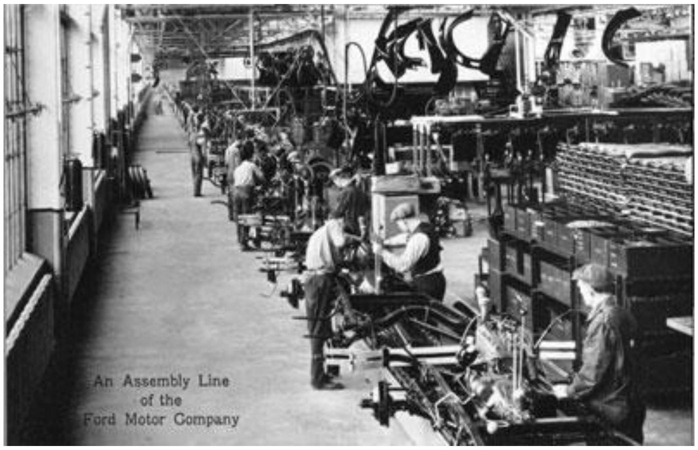

Figure 1: Ford Motor Company Assembly line in 1913. The accelerating speed with which Ford could produce cars helped him continue to lower the price of the Model T.[2]

1.2 Advanced Science Laboratory

Ford’s Dearborn advanced science lab (Figure 2), started in 1951, was not considered a heavy hitter corporate laboratory as seen at Bell Labs, General Electric, and IBM’s Watson Research Center. During the mid-twentieth century, these forward thinking institutions sought to work on topics not directly linked to the profit stream of the company, yet furthering knowledge for the good of everyone. [2] Ford recruited top scientific talent and funded both cryogenics research and nuclear magnetic resonance research through the 1960s. At this time, Ford researchers had more freedom to follow inspiration (even if it came from a small sample of supercooled phosphorus doped silicon). The idea that the superconducting quantum interference device, or SQUID, was developed at Ford research might seem far-fetched and not quite in the automotive sphere. However, it was John Lambe, James Zimmerman, Arnold Silver, Robert Jaklevic, and James Mercereau (Figure 3) who developed the SQUID at Ford Scientific Research

Figure 2: An aerial shot of the Ford Motor Company’s Scientific Research Laboratory in Dearborn, MI, in 1967. Current Research and Innovation building was expanded in the 1990’s.[2]

Laboratories almost by accident. Lambe made the first serendipitous observation of a magnetic resonance spectra of a 4K supercooled silicon sample. Mystified, Lambe consulted colleagues at Ford and Mercereau, who had just returned from a low temperature physics conference and where he met Brian Josephson, put forward the idea that the silicon sample was a Josephson junction. The resulting research and development of the SQUID was published in Physical Review Letters in 1964. Although the squid research produced 25 peer-reviewed papers and 9 US patents Ford Motor Company did not directly seek to develop the SQUID further. However, after moving to Aeroneutronic, a Ford owned company; Zimmerman worked toward advancing the SQUID and started his own company discovering many applications in diverse fields.[2,3]

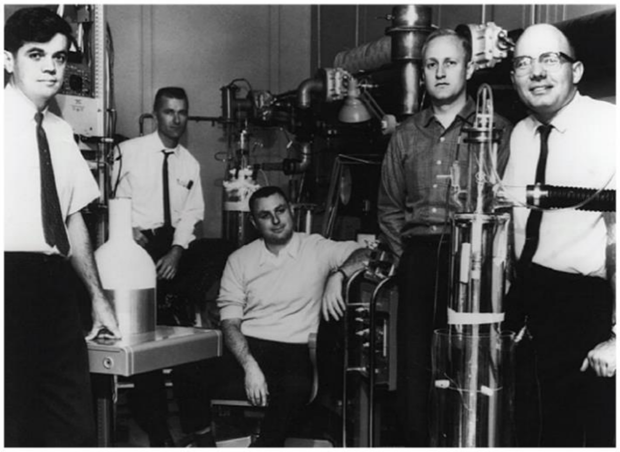

Figure 3: Ford's Team of researchers who developed SQUID technology: [from left] John Lambe, James Zimmerman, Arnold Silver, Robert Jaklevic, and James Mercereau.[2]

2. SMART MATERIALS IN VEHICLES

A key to advancing smart materials in automotive industry is to capitalize on applications where there will be an advantage over traditional methods. More specifically, this could include lightweighting, enhancing the driving (or riding) experience, or introducing innovative manufacturing methods. Typically, the high cost of smart materials is the primary reason they are not more widely utilized in the automotive industry.

2.1 Shape Memory Alloys

For over 30 years, Ford Motor Company has been identifying cost-effective uses of shape memory alloys for automotive applications including hydraulic line couplings, greenhouse window openers, plumbing type connectors, and thermally activated switches. The advantages to simplifying complex mechanisms, improving overall vehicle durability make shape memory alloys, in theory, desirable for automotive use.

2.2 Thermoelectrics

Similarly, Ford's research on thermoelectrics dates back to the 1970s. In the 90's the US government instituted CFC restrictions, eliminating CFCs by 1995 and motivating engineers to find alternative methods of mobile air conditioning.[4] Various methods of mobile air conditioning were tested at Oak Ridge National Laboratory including a thermoelectric cooling system.[5] The TE system tested could handle steady state cooling without the use of a coolant and did not produce CO_2 during operation. However, the system tested was not rapid enough to decrease the temperature of vehicles after a soak (Figure 4 shows a model of in-cabin thermocomfort) in the hot sun and as a result, the lack of transient cooling disqualified TEs from becoming the sole source of temperature regulation in a vehicle's cabin.[6,7]

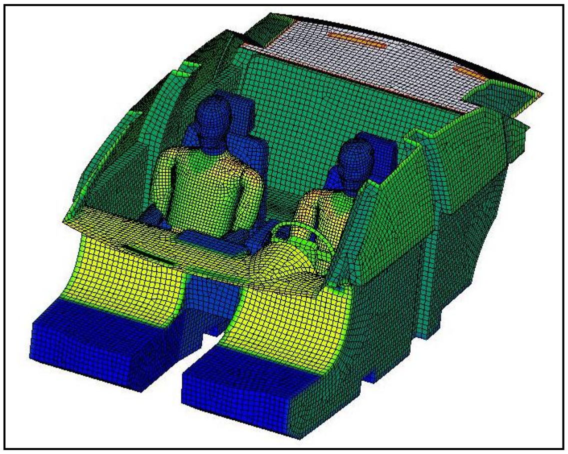

Figure 4: example of comfort model validation using CAE to model Ancillary Load Reduction Impact to optimize cabin HVAC design.[7]

Figure 5: Ford's autonomous vehicle development with integrated LiDAR.[13]

Ford Motor Company worked with suppliers and additional OEMs on two DOE sponsored project focusing on thermoelectrics for comfort and waste heat conversion. In both projects, cost, manufacturing at scale, and durability were major factors preventing wide spread utilization of thermoelectrics. The goal of both projects was to minimize energy usage, saving fuel for internal combustion engines or extending range for electrified vehicles.[7,8]

2.3 Magnetorheological Fluids

On-demand control of suspension allows the vehicle to respond intelligently to changing conditions. Semi-active suspension dampening system, often known as MagnaRide, is likely the most widely used magnetorheological (MR) technology. The latest generation of the MagnaRide suspension dampening system uses two coils wound in opposite directions, which are employed to tune the MR fluid, varying the viscosity, down to a 13 ms response. Vehicles enhanced with the semi-active dampening system (including the Camaro, Mustang GT, Ferrari, and Lamborghini) are currently found in higher-end sport cars; typically, these technology enhancements include an increased price tag for a slight edge over the competition. Incremental advancements and improved understanding of how to optimally utilize and manufacture MR fluids will eventually trickle down into less expensive vehicles enhancing NVH (noise, vibration, and harshness) such as the active-dampening system, hydrobushings, and hydromounts.[9,10,11]

2.4 Magnetorheological Elastomers

Although semi-active vibration dampening using MR fluids improves NVH, the performance degrades due to sedimentation of suspended magnetic particles in the fluid over time, leading to reduced durability. Similar semi-active dampening enhancements are achieved by suspending magnetizable particles in an elastomer creating a more stable solid-state version of MR fluids. Magnetorheological elastomers, made from natural rubber and iron particles, has an improved field dependent vibrational dampening effect when vulcanized under an applied magnetic field. MR elastomers have the potential to be used as drop-in replacements for tunable control arm or suspension bushings in a production vehicle reducing break roughness or improving transmission shift quality through softened fore-aft motion. Interestingly, MR elastomers are beneficial during the design process and are utilized to implement a specific machine design thus reducing development time. Additionally, tunable MR elastomer bushings enable automotive designers more freedom in suspension compliance for wide-ranging conditions when considering the ever-present compromise between handling and a smooth ride.[12]

3. FUTURE OF MOBILITY

3.1 Smart Vehicles

The automotive industry is moving toward increasingly connected vehicles such as autonomous vehicle using LiDAR (Figure 5) and in recent years, this connectivity has greatly accelerated. Ford Motor Company is in the business of moving people and goods; however, to do this the in the near term vehicles need to be smart and connected. While becoming more connected to the environment (Figure 6), to phones, to individuals, and to the cloud there is an increasing necessity for smart materials. In the near future, vehicles will use deep learning to accumulate intelligence and learn how to interact with analog systems such as traffic lights, signs, and yellow and white markings on the road. Further down the road, our analog environment will communicate with the vehicle creating "smart vehicles in a smart world".[13]

Figure 6: In the not-too-distant future environment will communicate with the vehicles, detailing road, weather, pollution and other conditions.[1]

3.2 Smart Factories

Future smart vehicles at Ford will be manufactured via intelligent and transformable factories in order to remain competitive. The smart manufacturing system will facilitate production starting with virtual factory integration. Optimization of the assembly line process, conceived of by Henry Ford, continues the forward thinking integration of new technologies such as smart materials onto the factory floor. New manufacturing machine integration will focus on human centered design helping assembly line workers with efficiency and safety while reducing the factory footprint.[1] Smart materials, additive manufacturing, and origami folding have the potential to revolutionize automotive manufacturing (Figure 7) as well as improve our experience with vehicles.[1]

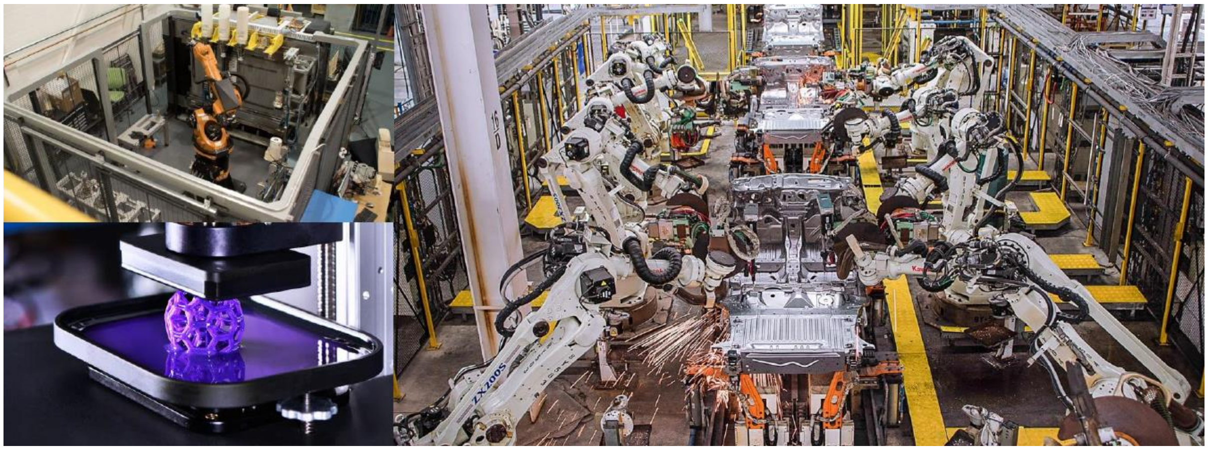

Figure 7: Factory of the Future will need to be more agile with a smaller footprint, faster logistics, and improved connectivity with a human centered approach.[1]