Composite Hood Jig for Automotive Assembly Process

Eric Leonhardt
Vehicle Research Institute
Western Washington University
eric.leonhardt@wwu.edu

James Waltman
Adam Aircraft
james.waltman@gmail.com

Venkatesh Iyer
Accenture
venkatesh.x.iyer@accenture.com

Abstract

A carbon fiber composite cross car hood jig is used to locate and install the hoods on the current model Ford Mustang. Vehicle Research Institute (VRI) students and faculty developed the composite tool to address ergonomic issues, reduce installation costs, and decrease cycle time. The application of a carbon fiber composite assembly tool represents one of the first implementations of this type of construction in high volume automotive assembly. Assembly specialists tested a prototype tool for durability and repeatability against a conventional steel fabrication. In response to user input, students further improved the durability and precision of the composite tool. For this project, students have developed a fabrication process that joins carbon fiber to aluminum inserts to hold tight tolerances over a 1.4 m distance. The construction method reduces mass to roughly 40 percent of the original steel fabrication. The low mass of the tool allows the tool to be used by one person without the need for an overhead crane balance, thereby reducing ergonomic concerns and supporting a faster, safer hood installation. Although the materials cost for the composite tool is higher than for a steel fabrication, the elimination of the crane balance reduces the overall cost of the assembly station. The project demonstrates the feasibility and benefit of using composite structures in non-aerospace environments. Other assembly workstations may gain from the appropriate application of composite tooling. In addition, students experienced the challenge of introducing new technology into a competitive assembly environment.

Introduction

The Vehicle Research Institute (VRI) at Western Washington University is located in Bellingham, Washington, approximately 90 miles north of Seattle. The VRI is part of an Engineering Technology Department that offers undergraduate degrees in Industrial Design, Manufacturing Engineering Technology, Plastics Engineering Technology, Electrical Engineering Technology, Technology Education, and Industrial Technology. Approximately 550 students attend courses in the department More than 125 students pursue coursework in the VRI to obtain a BS Industrial Technology degree. Students within the department share a common core of engineering courses.[1] Courses in the VRI curriculum expand upon the core to cover engine and vehicle design, development, and manufacture. Coursework mixes lecture and lab experiences with an emphasis on project-based education. The projects include instructor led team projects, student led team projects and individual projects. The instructor led projects involve designing, building and testing full size vehicles, such as the Viking 32 parallel hybrid safety vehicle[2]. Student led team projects include the Formula SAE[3], or Mini-Baja vehicles. Individual or small group projects may include projects for clients within corporations such as PACCAR, DaimlerChrysler or Bentley.

Students in the Vehicle Research Institute are exposed to the design process during the introductory ETEC 110 Engineering Design Graphics Course.[4] This course utilizes the work of Dym and Little[5] to explore the design process. Additional core courses such as ETEC 223 Machine Metal Processes, ETEC 333 Polymer Technology and ETEC 334 Reinforced Plastics/Composites[6] introduce students to the fundamentals of machining and composite construction. Within the Vehicle Research Institute, students apply their basic skills to a wide variety of problems and projects related to vehicles. As a result of the difficulty of the projects, the students are forced to improve their skills and techniques. Students develop expertise in computer aided design tools, high speed machining and composites. The projects challenge students with ill-structured and open-ended problems that prepare them for the experiences they will likely face as professionals in industry. Recent projects include an ultra-lightweight kayak used to set a world-record and a bio-methane scrubber used to allow methane from cow manure to power a vehicle.[7]

This paper describes a project that demonstrates how the skills students develop at the Vehicle Research Institute apply to an industry problem. The project is similar to a capstone project in scope, but occurred over a shorter time frame. This project is unique in that it is one of two global applications of composite tools designed to improve the automotive assembly process. It is the only example developed by students and used within North America. The paper reviews a problem faced during the Ford Mustang launch, the approach the authors took, the implemented solution and its challenges, and the outcomes for students.

Problem

The launch of the 2005 Ford Mustang offered a unique opportunity for students at the Vehicle Research Institute to improve their design and development skills. The Ford Mustang launch team faced a challenge installing the hood on the vehicle at the Auto Alliance International (AAI) plant in Flat Rock, Michigan. The team planned to use a welded, square tube jig to support the hood and align the hood with the vehicle. An assembly technician would locate the jig on the front strut tower and the radiator support structure. Figure 1 displays the locating points on the vehicle below.


Figure 1. Positioning features for hood jig.

Once located, the jig would help position the hood while the hood was fastened to the vehicle. The primary challenge facing the team was that the hood jig alone weighed 16.8 kg. It became clear that a single operator using the jig would be lifting more than the recommended weight limit for an eight hour shift, based on the NIOSH factors.[8] A potential solution was to add an overhead balance--a type of hoist--to the operation. The addition of the balance required an order of magnitude capital upgrade cost to the assembly station (Venkatesh Iyer, personal communication, June 19, 2006). In addition, the use of the balance slowed the hood installation operation. Also, the authors' have observed that assembly technicians often bypass the balance assembly aid in an attempt to decrease the installation cycle time. This tradeoff comes at the risk of injury to the operator. Another option considered by the team was adding a second assembly person to the operation. Members of the launch team were interested in finding an alternative solution that could provide advantages to the assembly operator and to the assembly process.

Approach

The authors utilized a problem solving process similar to that outlined by Dym and Little. Team members:

- gathered requirements;
- reviewed the available materials and technology;
- engaged in creative ideation;
- selected two concepts for refinement;
- modeled the concepts using a CAD tool;
- planned the manufacturing process;
- selected and refined a prototype tool for manufacture;
- machined components;
- assembled a prototype;
- field tested prototype;
- refined design; and
- manufactured two additional tools.

The authors desired to create a tool that could be tested within a few weeks, rather than optimizing a design and delaying prototype fabrication. This approach would allow the launch team to evaluate the composite tools' potential as rapidly as possible.

Requirements

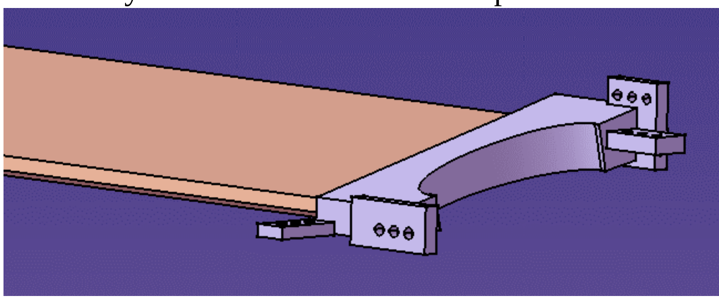
The authors determined the following requirements from discussions with the launch team. The prototype hood jig would need to:

- meet the geometric dimension and tolerance goals of the steel jig (+/- 0.015 mm);
- reduce mass by a minimum of 50% (8.4 kg vs. steel jig at 16.8 kg);
- survive repeated drops and abuse on the assembly line;
- be repaired by plant personnel;
- be delivered within a few weeks; and
- obtain approval from assembly technicians performing the operation.

Prototype Creation

Meeting the deadline for an initial prototype became the driving requirement. Without meeting the deadline, the vehicle launch team might not consider a composite tool solution. Part prints for the original tool were obtained during the first week of June, 2004. By the second week of June, two of the authors designed the initial prototype using the CATIA V5 computer aided design package. Images of the tool were sent to the launch team for a quick review. Tooling was ordered during the second week of June, while a student began creating the manufacturing and assembly process. Based on the manufacturing and assembly process, several detail design changes were made to facilitate machining and assembly of the jig. The initial prototype was sent to the launch team during the second week of July, to be used in a pre-production build of the vehicle.

The compressed timeline drove students and faculty to select construction techniques that were well developed at the Vehicle Research Institute. Additional time was saved by using steel detail parts designed for the original steel tube jig. Significant weight could be saved over the final design by optimizing all of the components. However, in doing so the time constraint would not have been met. Several concepts were sketched and two were modeled in CATIA V5. Figure 2 shows an initial design concept below. The selected design involved a base of three components upon which additional detail locating features were bolted. The base utilized a center section of prefabricated, 10 mm thick carbon fiber faced aramid honeycomb core.[9] This aerospace flooring material was chosen for its stiffness, low density and immediate availability in sizes of around 200 mm x 1100 mm. Carbon fiber offers the tensile strength of 1724 MPa to 5033 MPa, depending upon which production process is used.[10] The Young's modulus of Carbon fibers may range from 228 GPa to over 700 GPa.[11] Carbon fiber structures may have a mass 20% of steel with equivalent strength and stiffness. Two wrought aluminum end pieces were machined and adhesively bonded to the carbon fiber panel. The initial base weighed 3 kg.



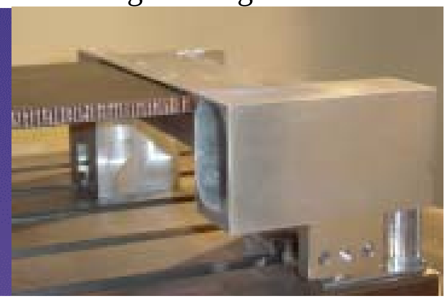


Figure 2. Carbon fiber panel bonded to aluminum end. Figure 3. Hood jig fixture.

The steel hood jig design required positioning tolerances on all locating pins of +/- 0.015 mm over a 1280 mm distance. For prototype parts created with students and faculty, this tolerance is normally reserved for a bearing or cylinder bore over a limited distance. The distance posed a challenge because the key locating features were beyond the travel of the vertical machining center used to make the aluminum parts. A solution was developed by machining the aluminum end pieces and bonding them to the carbon fiber center section. A locating fixture was machined on the edges of the machining center's bed. The fixture depended upon the machining center's positioning accuracy to machine pin locations. Fortunately, the geometry and features of the aluminum end plates on the hood jig allowed the end plates to be located by the locating fixture on the bed of the machining center. Before the Loctite E-120HPepoxy cured, the assembly was positioned on the locating fixture and left to cure, as in figure 3 above. The use of epoxy allows dissimilar materials to be joined while distributing load more evenly than mechanical fasteners.[12] This process provided the most accurate location given the limitations of the machining centers and coordinate measuring machines available. A coordinate measuring machine at the AAI facility found the prototype dimensionally acceptable.

Positioning accuracy affected the design of the aluminum ends of the jig. Initially a contoured, light weight piece was considered as pictured above in Figure 2. The final design allowed all critical locating holes drilled and reamed while the raw stock was located in one position. Holes perpendicular to the main datum plane were machined in the same operation using a right angle head. Most of the raw stock was removed with a 50.8 mm RPF (rough, plunge, finish) tool body with tungsten carbide inserts. Cutting parameters of 64 mm/s, 6500 rpm and a depth of cut of 3.8 mm kept removal rates within the limits of the machine tool and fixture stiffness. A height difference between the highest plane and the deepest pocket on adjacent surfaces of the part limited the size of cutting tools and kept the part radius on the pocket larger. The initial aluminum ends weighed 1.08 kg. Additional design iterations demonstrated that detail changes such as the smaller radius sizes on pockets could drop the weight to 0.9 kg. The required changes in tooling and manufacturing process were rejected due to time constraints.

Implemented Solution and Challenges

When the base arrived at the AAI facility, steel locating features were bolted to the structure. The mass grew from 3 kg to 7.8 kg. This compared favorably to the reported 16.8 kg mass of the steel assembly jig. Later, aluminum details replaced the steel details on two subsequent hood assembly jigs. These production hood jigs weighed approximately 5.4 kg; nearly 40% below the target mass of 8.4 kg.

After several tests, the launch team decided that the 10 mm carbon fiber paneling was not stiff enough. As the center section flexed, steel locating pins rubbed causing the tool to hang up on the car. The prototype was returned for modifications. Two box section stiffeners and two u-shaped channels were created in carbon fiber using a single machined aluminum mold. The stiffeners spanned the length of the carbon fiber, Nomex-cored panel. The u-channel pieces were added to the prototype to close out the edges of the panel.

Several cars were built with the jig. Users of the jig requested a small change to the handles of the jig. Following the tests, the launch team observed cracks that had formed near one of the open ends of a stiffener. A student developed a repair kit with step-by-step instructions including numerous pictures. The instructions detailed how to measure, mix and apply the epoxy and a carbon fiber patch to the cracked area. The crack was successfully repaired on location.

As production of the vehicle increased, two additional hood jigs were ordered. Two new hood jig bases were delivered just ten days after the initial order. The new hood jigs featured an improved, full radius stiffener on the underside. The new stiffener benefited from a dedicated aluminum mold that allowed the ends of the stiffener to be closed with a spherical surface. The mold dramatically improved the surface finish of the stiffener while additional layers of carbon fiber increased rigidity and strength. The improved stiffener eliminated the cracking problem found on the prototype.

Outcomes

In May of 2005, members of the hood jig design and construction team visited the AAI facility to view the hood jig in use. Of the three hood jigs available in the facility, the prototype was used in the repair area while one of the more refined hood jigs was used on the main assembly line. The third jig was kept as a spare. The students were pleased to see a single person locating the hood to the vehicle without aid. The operator praised the students for the lightweight, stiff construction. At that point, over seventy five thousand vehicles had been produced without incident using a single composite hood jig.

At the time of this writing, over two hundred eighty thousand vehicles[[13]] have been produced using a composite hood jig. The implementation demonstrates that a carbon fiber reinforced tool can withstand the rigors of an automotive assembly environment. The success of this project also offers a guide for pursuing additional assembly aids created from low density, high strength composite materials.

As a result of this experience, students have become involved with several similar industry sponsored projects at the Vehicle Research Institute over the past two years. The projects pair a client need with an individual student leader. The student leader may work with a small group of students (one to three) to create the deliverables. The student leader may obtain Independent Study credit for the project. The client and project may occur at any time during the year, which may not concur with the academic calendar or activities. Typically the projects range from one to three months. The success of the project depends upon matching the student's skill set, aptitude and work habits with the type of project. Success also depends upon monitoring of the project by faculty. Students benefit from the projects by honing their design and prototype manufacturing skills. In some cases they have dramatically improved their skills in a specific domain such as CNC surfacing. Perhaps more importantly, the students directly respond to the needs of an industry client and are responsible for meeting and managing those needs with the client. A portion of the income generated from the project may be used by the students to fund the student team projects, such as Mini-Baja or Formula SAE. Finally, students have gained exposure to potential employers and have used their project portfolio to obtain employment in their field of interest.

Future of Composite Tools in Automotive Assembly

Several questions may help guide the selection of carbon fiber composite tools as an alternative to traditional steel structures:

1. Are the operators and technical support personnel willing to test a new approach or material?
2. Is it possible for a lightweight tool to eliminate a mechanical assist device and still fall within ergonomic guidelines for a safe workstation?
3. Can the assembly aid be easily designed and built with building block style materials such as CreForm©?
4. What quantity of tools is required?
5. What environmental conditions will the part encounter?

Automotive assembly plant personnel are often faced with a wide variety of complex automation with different life cycles and supporting legacy equipment. They must be willing to support a new fabrication process. Eliminating a mechanical assist device will dramatically lower the cost of an individual workstation. In most case the operator will be able to perform an assembly operation faster without the mechanical assistance. A lightweight tool may redirect assembly workers to installing additional parts on the vehicle, rather than helping to support or move large assembly aids. Building a tool with CreForm©, a product similar to giant Tinker Toys©, allows plant personnel to quickly build, test and modify assembly aids with simple hand tools. The process eliminates dependence on external shops, provides flexibility, and reduces the time required to respond to vehicle or part supply changes. Composite assembly tools would be uniquely designed for their purpose, which offers them an advantage in low mass and efficiency. This limits their flexibility and requires an outside supplier for design and construction. Composite tools have high material costs and long fabrication times relative to competing steel tools. A hood or door prop that travels with the vehicle through many workstations may be better served by a stamped sheet metal or bent steel rod piece that can be quickly made in hundreds of units. A part that must travel through the paint ovens must survive high temperatures. This can be achieved with a careful selection of resin systems, but is easily achieved with more traditional metal fixtures. Environmental conditions with temperature swings may favor composite tools. Composite tools may be produced with low coefficients of thermal expansion. These considerations may help determine whether composite tools should be considered in an assembly process.

Conclusion

The successful implementation of the carbon fiber hood jig demonstrates a new potential use for high performance composites. In areas where ultra light tools can reduce ergonomic concerns and eliminate more costly assist devices, the low mass and high strength composite materials offer a significant advantage. The process of introducing a new application for composites in a time sensitive manner proved particularly rewarding for the former students and authors involved in the project.

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