

PlyMatch – A Ply Placement Visual Aid

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ABSTRACT

When manufacturing high quality composites parts that are both weight sensitive and able to carry the loads imposed on them by their working environment, the individual plies have to be laid into or onto the mould accurately in the correct sequence and in the correct orientation. In the modern manufacturing environment ply placement aids are required to assist the operator to perform those tasks. This paper details a new and innovative method based on augmented reality and commercially available under the brand name PlyMatch. Developed by Anaglyph Ltd following a wide research programme, the system not only helps the laminator to orientate the ply in the correct place on or in the mould but also is able to make sure that the operator is laying those plies in the correct sequence. In addition, all the actions can be recorded on video for quality assurance purposes and subsequent analysis to ensure that the part has been made correctly, something that is safety critical in an aerospace environment.

The advantages PlyMatch confers to operators of the equipment and how it can be driven in different ways dependent on the systems in place within a user environment will be described. Also, how it will interface with all packages on the market and provide the customer with all their requirements in one system. It will describe alternative uses for PlyMatch such as its use as a substitute template utilising already generated CAD data and as a wireless CMM. The system is a safe cost effective and versatile way of obtaining accurate parts.

INTRODUCTION

Composite parts in prepreg have been manufactured for many years by hand lay-up. These parts have been destined for high performance applications as varied as aerospace, motor sport, high end automotive use, high performance yachts, powered speed craft, space and defence. All these sectors are safety critical where the consequences of failure have severe repercussions and can potentially lead to the loss of life.

These parts will be both weight sensitive and will carry high mechanical loads. Production numbers of these parts has risen as their market penetration has increased and reproducibility of parts is a key requirement. Historically this necessitated finding a way to assist the operator to lay the prepreg both in the correct place in or on the mould and in the correct sequence. The first systems on the scene were lasers where the image of each ply was projected directly onto the mould. Over time mouldings have become increasingly complex due to a number of factors such as the desire to save even more weight in the drive for mechanical efficiency. This has lead to moulds

with deep cavities and steep sides where it is difficult for lasers to accurately project the ply outline without incurring serious inaccuracies. As a consequence waste increased due to parts that had been incorrectly manufactured.

When producing prepreg parts of any description, the laminator requires certain things to allow them to accurately reproduce the laminate as designed. Apart from the tool and the prepreg, they need a ply book or a drawing, a ruler, a suitable pencil, a sheet of paper and maybe a metal template. Whether they need to use all these items depends on the complexity of the part and the customer. As parts become more complex, the skill levels of the laminator increase. If a part incorporates island plies i.e. ones that do not start from any edge of the mould then the degree of difficulty rises significantly. This is where templates may be employed. Measurements may need to be taken and maybe the use of plumb lines needs to be included to ensure that each ply is located correctly both in relation to the previous ply and in relation to the mould. Also needed is for the laminator to ensure that the traveler that will accompany any part is suitably completed. This can range from ticking each layer as it is laid into the mould to signing the sheet at significant points in the part construction and when the part has been completed. The above procedure in part or in full is utilized when making these parts in all the industries using prepreg. Additionally, many aerospace parts in the past have traditionally consisted of several layers of prepreg laid into the mould, the part cured and then the excess material machined away to leave the desired part. This is changing as the aerospace industry is starting to demand that these parts are designed in a different way and if less material can be used and the parts made thinner maybe by the use of island plies to meet mechanical property considerations then they will be made that way. This of course presents problems to those companies currently making these parts. Skill levels to make them the current way are low but to make them the way described above they will need assistance to ensure that they are made correctly.

To meet the demands industry has invested in technology. As parts have got larger, automatic methods of construction such as tape laying have replaced hand lay up as the primary means of production as it became impractical to lay long lengths of prepreg into or onto a mould. This has also been driven by economic factors because any part with a high labour content becomes very expensive particularly ones produced in a high wage economy. But large numbers of smaller parts are still produced by hand. Within the aerospace and auto sport markets ply placement aids have evolved to assist the laminator in placing the prepreg plies in the correct orientation and correct sequence. The major portion of the market to date has been captured by lasers with the units installed above the mould in a fixed position and the outline of the ply being projected onto the mould tool.

Anaglyph Ltd saw this problem in the course of its work with composites design software and after widespread research invented an alternative solution. The new method is based on augmented reality with a set of equipment that allows the projection of the ply image onto a screen which carries a live video feed of the mould. The responsibility for producing the part still remains with the operator but the equipment should be viewed as an aid that allows the laminator to retain their core skills whilst laying the prepreg ply in the correct place and the correct order. A customer case study will be presented to provide background to the choice and use of the equipment.

The system can also be used to place dry fibre material into moulds for complex Resin Transfer Moulding work.

HOW WAS PLYMATCH INVENTED?

EQUIPMENT DESCRIPTION

The equipment is portable, relatively light and simple to set up. It consists of a digital camera, a sensor, probes, a monitor, a CMM incorporated into a computer and a wireless calibration probe. The equipment also comes with a number of optional extras and for the purposes of this paper we will assume use of some of these extras. The digital camera is a simple unit with the ability to zoom in and zoom out with a x2 magnification and is a compromise between capability and cost. There are two probes which are attached to the camera and to the mould. One is a T shaped probe, the other a star shaped one. Both have Light Emitting Diodes (LED's) built into their bodies. Again they are compromise between price and capability. The sensor is 800mm wide and is able to "see" the LED's in the probes via infra-red sensors in windows that are found at either end of the sensor and in the middle of it. A wireless calibration probe is required to locate the mould in space. The computer has specially developed software called Placement loaded into it. This software is what drives the augmented reality and projects the outline of the ply to be laid into or onto the real time picture of the mould being displayed on the monitor.



Figure 1



Figure 2

EQUIPMENT SET UP AND USE

Equipment Layout

Setting up the equipment is relatively simple. The digital camera is mounted and held securely in an aluminium "U"-channel. The "T"-probe is then attached to the "U"-channel. A universal joint is attached to the assembly via an interconnector threaded into the bottom of the camera. This universal joint connects to the camera boom. The digital camera is positioned over the mould and connected to the computer. Use of the universal joint allows easy movement of the camera during ply placement operations. The "star" probe shown in figure 1 is attached to the mould either via a hard attachment or a soft one. A hard attachment is one that fixes to the mould via two

small nuts and bolts and means that the probe is attached at the same place every time that mould is used. A soft attachment uses double sided tape or plasticene for instance. When this is done the probe will be located in a slightly different place each time. Use of the latter method is often used when manufacturing a very complicated part such as a car chassis and it becomes necessary to relocate the probe at times for production reasons principally because the laminator obscures the probe in the process of laying the prepreg. The probes are fitted with Light Emitting Diodes (LEDs) at the tips. Both these probes are viewed using the CMM sensor that “sees” the LEDs and both probes are connected to the computer. The CMM sensor (shown in figure 2) is mounted on a stand and connected to the computer. The CMM sensor has a viewing range covering an envelope of about 5m by 2m. It is placed about 2m away from the mould at a height of about 2m so that it can see both the camera probe and the probe attached to the mould. A monitor is connected to the computer and is placed in front of the laminator when they are manufacturing the part so that the laminator can clearly see the screen. The wireless probe comes with several tips and an extension. For our process we use the extension and a pointed tip. The probe has two buttons on its body to record the calibration information via the CMM sensor.

Use

Once the equipment is set up for use as described above everything is switched on and the Placement software is allowed to boot up. A live video image will be seen on the monitor. The camera is then moved to display the image of the mould. Each time the equipment is used the equipment calibration is checked by using a file called DRF.DAT. This is an outline of the “star” probe attached to the mould and may be the first time the user sees the “augmented reality” in operation. When the DRF.DAT file is called up and the camera is pointed at the probe the outline should overlay the probe exactly and when viewed from several angles should remain overlaid. If the probe outline appears to be in the wrong place (any misplacement will be small) it is possible to use one of the windows to move the image to the best position.

Next the mould has to be calibrated to locate it in space. The wireless probe is used to carry out this procedure. Three easily located known points on the mould taken from the CAD model are chosen that are not going to be covered with prepreg for the calibration. Within the Placement software is a calibration window. Using these coordinates and the wireless probe, the calibration procedure is completed. Typical points could be intersecting lines or laser points on the mould surface. If a hard installation of the probe to the mould has been chosen then this calibration can be used every time that particular mould is used by saving the first calibration. If a soft attachment has been used then the mould will need to be recalibrated each time it is used. The calibration is, however, easy and takes less than a minute to complete.

The next stage is to load the files for the plies to be laid into the mould. A text file is compiled listing each of the plies to be laid. The ply information can be either 3D-DXF or IGES files. The latter are in common use generated within industry standard software, the former can easily be generated again using common CAD programmes. Once the text file has been loaded, the first ply outline will appear on the screen located over the live video image of the mould. The laminator is then set to start laying prepreg which they do in the normal way except that instead of operating head down looking at the mould, they look at the screen in front of them. When the first ply

image appears on screen, the ply numbering system is provided discretely at the bottom of the screen. Since the mould has been calibrated in the CMM system, the mould can be moved about as often as necessary provided the CMM sensor can still see the probe. For small complex parts this is especially useful to ensure that the prepreg sits in or on the mould in the correct position. The ply outline will move with the mould in real time as the camera is relocated during the lay-up procedure. A hard attachment of the probe is, however, desirable to do this as a soft attachment could easily get knocked resulting in an incorrect position of the ply.

To assist the lay down procedure other functions are incorporated into the software. It is possible to zoom close in when there are difficult areas to be laid down. This is a times two zoom. The image can be inverted so that hand movements during the prepreg laying follow the natural left to right movements of the hands. Both these tools allow the operator to easily transition to using the equipment. All the work being viewed on the screen can be recorded. It is recorded at a slow frame rate at a slow frame rate of between one and five frames per second, the recording rate being set by the operator in the appropriate window. This keeps the volume of information to a manageable level. A little flashing image on the screen shows the operator that recording has been activated. The size of the avi file recorded in slow time means that all information would easily fit on a CD for retention in any normal filing system. This recording serves a very useful purpose. During development of a part one can ensure that the plies have been laid in the correct sequence and in the correct orientation and when the part is tested maybe to destruction one can be completely sure it was produced correctly. If PlyMatch is used as a production piece of equipment then the video sequence can be used as a quality assurance measure again ensuring that the part has been produced correctly. Within aerospace or when licensing production, the video recordings can also be used as part of a new operator training syllabus.

When working directly with Laminate Tools, or with DXF files that have been produced by Laminate Tools, the type of ply i.e. cross ply or unidirectional is also displayed both in the ply information at the bottom of the screen and pictorially when either the image shows coloured unidirectional lines on the image or it shows a cross ply with the ply image cross-hatched. It is also possible to highlight those areas in either red or amber where there is a high likelihood of the ply either thinning during ply placement or wrinkling due to a small radius of curvature on the part. For experienced laminators this is very useful information particularly if it is the first time this part has been manufactured.

For some very complex operations, it is also possible to be able to cut the prepreg on the mould and hence to obtain a 2-D template of the prepreg ply. This is a form of reverse engineering. It may be that the original ply although cut correctly does not fit or the ply outline has not been generated in a software draping tool and this capability is very useful.

Lasers systems tend to be fixed in one place and once installed in a room the tool has to be brought to the laser. Plymatch is a portable system able to be assembled and disassembled quickly and easily and relocated. The only thing to ensure when reassembling is that the sensor does not face strong sunlight or strong artificial light otherwise exactly the same as with the readers' eyes, it can be dazzled. It is also

basically maintenance free. Full draping information such as splits can also be shown on screen.

ALTERNATIVE USES

Alternative uses of the system have emerged during trials with the equipment. It can be used as a template for either locating other parts during an assembly procedure or for drilling holes. It can also be used to mark difficult shaped parts with markings. It can mask highly curved parts prior to those parts being subjected to surface treatments such as anodizing and alochroming. The information that is required to do so needs to be created within a CAD system but is likely to have been done so anyway during the design of the part. In summary, anything that has been created within a CAD package will work seamlessly in Placement. With the appropriate software it can also be used as a wireless CMM being able to generate CAD data either of the mould or the part or any other part.

ADVANTAGES OF USING PLYMATCH

PlyMatch provides a number of advantages to manufacturers. It is flexible and excellent for producing highly curved parts particularly ones when movement of the mould is highly advantageous to being able to ensure that the prepreg lays into the mould correctly. It can show full draping details or other manufacturing data i.e. it is fully customizable. It allows work to proceed easily within cavities, something exploited fully by those autosport manufacturers making parts such as a racing car nose cone. The mould can be moved at all times without recalibration. The ability to video record all work can be regarded as a major plus for the system as described above. Single images can also be provided as part of the QA procedure.

It is versatile and can be used for quick templating as previously described. PlyMatch can be used directly with Laminate Tools or with any CAD system. Alternatively it can be used purely as a wireless CMM (Coordinate Measuring Machine) with the appropriate software. When used for dry fibre work particularly when very thick mouldings are being put together it can be of great assistance ensuring that the fibre pack has been laid up correctly and in the correct order.

As stated above it is possible to run the PlyMatch system through Laminate Tools as shown in figure 3. Companies see advantages to doing this. One major reason is that the same system can be used throughout the entire design and build process. The operational processes are very similar to those used for Placement. Information such as the reference direction and the best place for first point of contact when laying the prepreg ply are shown. Also shown are the areas in the mould where difficulties will be encountered when laying the prepreg. These will include areas of double curvature and corners and they are highlighted in either red or amber denoting very difficult to lay in place and where either wrinkles or prepreg thinning due to bridging are a possibility. It is also possible to use the package as a CAD package when dimensions are needed. The same processes encountered in Placement for calibration, recording etc are still used.

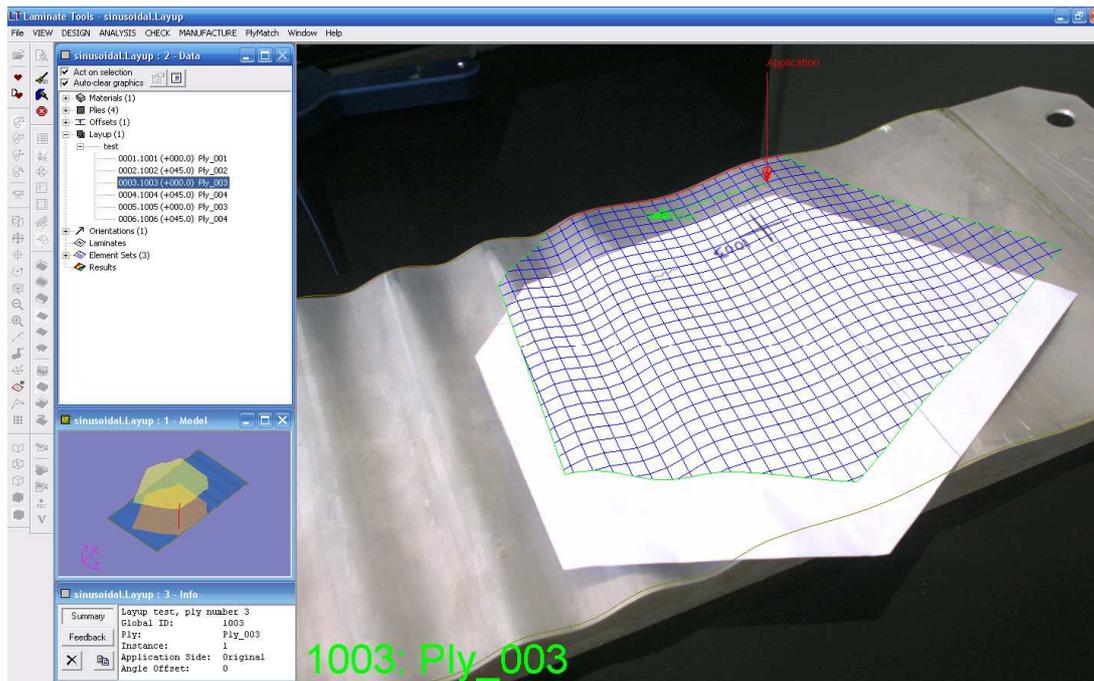


Figure 3 – PlyMatch being operated in the Laminate Tools Environment

OTHER ANAGLYPH SOFTWARE PACKAGES

Anaglyph offers three other composites design software packages, Laminate Tools, LAP and CoDA.

Laminate Tools is the draping software package mentioned above able to drive the PlyMatch system where one can build up the plies in the best way to the required thickness ensuring that they are laid with the minimum of disruption to each one in the form of wrinkles and prepreg thinning. It takes into account ply thickness during the build up of the part. Not only is it a design tool it is also a significant assistant to manufacturing being able to convert each of the 3D plies laid on to the tool into 2D shapes for subsequent use on the prepreg cutting table. It can also compile the ply book for use by the laminators in making the parts. It uses well tested draping technology and interfaces with industry standard finite element packages. Its time saving methodology allows for design verification and optimization. It minimizes material waste, highlights problems early in the design process before reaching commitment to tooling and prototype production and can reduce the need for expensive physical prototypes.

LAP (Laminate Analysis Program) and CoDA (Component and Composite Design Analysis) are Anaglyphs' other composites design software packages. Both are low cost pieces of software to aid composites designers speed up the process of component design. LAP can be used to analyse any type of composite laminate subjected to in-plane loads and moments. Since the flat laminate has no fixed size apart from its thickness the analysis can be applied to any composite component where loadings or deformations are known. Any composite combination can be analysed ranging from carbon fibre reinforced epoxy to glass fibre reinforced polyester. It can be used for preliminary design to tailor a stacking sequence then the design can be analysed using other methods. It is widely used in both industry and

academia and is easily understood. CoDA enables preliminary design analysis of components or sub-components with plate, beam, joint or flange geometries to be quickly and easily undertaken. It allows the rapid assessment of the effect of choosing different design solutions and gives a high degree of physical appreciation of the relative effects of choosing different design solutions. It has been widely proven in industry and provides highly accurate solutions to many problem parts and is applicable to panels, beams, joints and flanges.

CASE STUDY

Wirth Research is an innovative engineering group, founded by Nicholas Wirth in 2003. The team of engineers specialise in research, development, design and manufacture for the motor racing industry and other high technology sectors. In 2008 the company received a Queen's Award for Enterprise having achieved growth in export sales of 378% over three years. The outstanding achievement is the result of a small number of strategic partnerships, of which Honda Performance Development, Inc (HPD) is the main one. This partnership culminated in winning both the 2004 and 2005 Indy Racing League drivers and engine manufacturer's championships.

The partnership has now been extended into a multi-year agreement in the American Le Mans Series where the two companies jointly design and manufacture the Acura ARX-01b Le Mans Prototype chassis for four teams entered under the Acura brand. This year Wirth built cars are again on course to achieve outstanding success.

Wirth Research design and manufacture the high performance racing car bodies and every effort is made to ensure that they are manufactured as efficiently and cost effectively as possible using the minimum volume of carbon fibre reinforced plastic and achieving maximum mechanical efficiency. To meet their goals they required a ply placement assistance method to ensure that the island plies and inserts were laid in the right place with the correct tolerances. To achieve this goal without assistance would have meant many extra man hours expended using templates, rulers and calculators. After reviewing the available methods on the market, they chose PlyMatch because "it is the only system that can show ply boundaries inside female moulds". After careful consideration the system was chosen in February 2008. The parts they manufacture range from complete chassis to nose cones to brake ducts and all the other parts required to complete the car bodies.

In the same timeframe, they also carried out a market review of composites design software. They chose the software draping tool Laminate Tools also available from Anaglyph because it allows them to carry out all their design work without having a dedicated finite element analyst. They only operate PlyMatch using the Laminate Tools software package and they find that it allows them to rapidly change parts at the design stage and easily download the part production information without having to use any other software. The laminators quickly adapted to the system and find it is second nature to use it as designed. The system provides a clear indication of the boundary as well as material type and orientation for every ply together with a coloured highlight of any areas where difficulty could be expected laying the prepreg material into the mould. PlyMatch also illustrates the positions of inserts and honeycomb transitions. There is no need to mark out or measure anything during the lay-up process but they have the ability within Laminate Tools to use the system to

check accuracy of plies at any time. Such is their confidence with it that this now rarely happens. There is therefore no need for design to provide additional information to support such processes saving time and ensuring consistency as there are no interpretations made. The ply boundaries are exactly as defined in 3D by the designer and as analysed in FE.

SUMMARY

This paper has set out the history behind PlyMatch, describes the equipment that allows the system to operate and how that equipment operates. It also shows how, in the modern manufacturing environment, alternative hardware combined with simple to use but intelligent software exists to address issues and reduce potential waste. The case study presented is a brief overview of how one company chose the system based on software that in their view contributed to cost reductions versus the alternatives on offer. PlyMatch is an easy to use system which operators find comes naturally once any initial skepticism has been overcome.