Title:
Mold Geometry Analysis Tools for Fabric Material Handling System Applications

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Keywords:
Deviation, Mold, Surface Curvature Combs, Geometry Analysis, Fabric Handling

DOI: 10.14733/cadconfP.2022.404-409

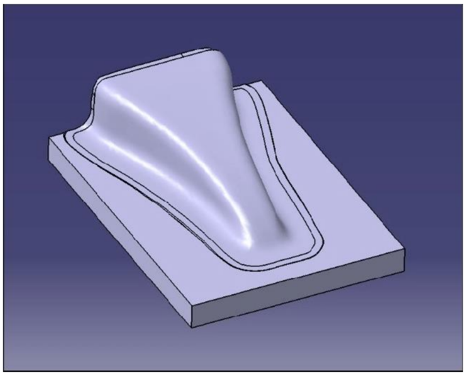
Introduction:
Introducing light-weight material solutions such as fiber composite materials to reduce vehicle mass is driving innovative research in several fields due to their high specific stiffness and strength compared to contemporary engineering materials [1,12]. Multiple fabric segments with differing materials can be utilized within a product [3]. The fibers cannot be damaged during handling. Consequently, this is a significant automation challenge as there are many issues related to automation strategies and handling methods for high production volumes [4,5]. There is no semi-automatic or automatic solution for rapid, efficient, and reconfigurable pick and place operations of fabric materials. Thus, material handling of flexible textile/fiber components is a process bottleneck as manual operations are typically employed [1].

To position and conform one or more textile patterns onto a mold to manufacture composite components, a manual method known as draping is used. Properties of the fabrics that determine its propensity to drape (including in-plane shear and bending, stability etc.) influence results, which also depend on the geometric features of the mold [6,11].

A mold and product (Fig. 1) example illustrate composite molds' shape complexity. As a part of this study, mold surface analysis tools are developed to highlight potential regions of concern via assessing surface normal variations and rates of change. This will provide insight for preforming [4], fabric segmentation, and placement activities. Surface softening tools are also developed to minimize vertical deviations of the mold surface [2] to facilitate specialty gripper designs [13]. The purpose of this study is to predict potential high probability wrinkle or problematic draping regions of the mold using surface analysis tools of SolidWorks and Rhino. This will provide insights for specialty grippers and handling strategies. The measurement criteria include surface normal variations and their rates of change [9].

In this study different types of surface contacts (bounding surfaces), and an application of several mold surface analysis tools including curvature evaluation, surface normal deviation, surface smoothness analysis, surface vertical deviation smoothening is introduced following up with the application of a surface flattening tool, which is required for developing a gripper-material handling strategy with a decreased probability of wrinkling or over-draping of fabric draping over mold surface.

Evaluation and analysis tools in this study are applied for a few typical mold surfaces for the sake of illustration and simplifying the understanding of the problem. However, they will be versatile and compliant tools that can be further applied in any sophisticated composite fiber industrial molding environment. The goal of this research is to provide tools that can result in smoother and potentially fewer problematic mold regions, or insights where fabric draping is an issue, which can be resolved at the design stages. This is to result in reduced out-of-mold deformation for automatic or semi-automatic fabric draping [8]. The effect of fabric properties on different mold geometries will be considered in future studies.

(a) 

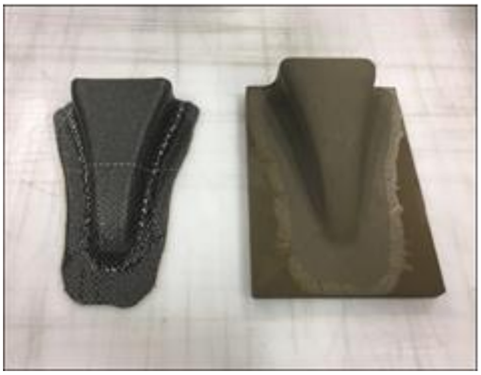
(b) 

Fig. 1: (a) A CAD model and (b) a sample of a mold used for fabric composite draping.

<u>Main Idea:</u>
Evaluating mold geometric features for mold surface redesigns, fabric panel designs (slits, holes, multiple fabric panels), and/or handling optimization is a necessary piece for understanding fabric-mold interactions for effective automated pick and place operations as well as the final product characteristics. Rapid proper fabric placements without wrinkling and fitting the mold surface is the end goal. Complex mold surfaces can be split into individual geometric features (base surfaces). These base surfaces can be identified in the CAD models by lines and edges, drawing distinct differences between features. Edges common to neighboring surfaces are used as direct links between the base surfaces. Each base surface is also identified through vertices, lengths, and radii. Individual geometric features include flat, single curvature, or double curvature [7,14].

Angle between surfaces
Sharp edges and corners should be avoided in a design as they can become problematic during draping, in terms of conforming the fabric to the feature. These features often force the use of darting, allowing the surface to be covered without wrinkling but increasing production time since cuts must be made through the patterns [9,10]. Preliminary shear is a proposed solution for mitigating wrinkling and eliminating the need for darting.

Corners and edges
Corners and edges that appear to have no fillets exhibit shearing characteristics that become problematic during draping. The angles between the surfaces contribute to the fabric's ability to drape over all three surface and determine how easy or difficult it is. When a fabric is placed on a mold's sharp edge and draped over the edges to cover all three surfaces, the warp and weft yarn orientations present conflicts with the alignment. Warp and weft yarns along an orthogonal crossed edge attempt to become parallel to one another. Wrinkling is often a result of the angle between the warp and weft either becoming too large or too small due to in-plane shear [1].

Evaluating Surface and Solid Quality by SolidWorks
Surface Curvature Combs
Using the Surface Curvature Combs tools from SolidWorks, the type of bounding surfaces can be illustrated by the direction and magnitude of combs. Fig. 2 shows four different bounding surfaces.

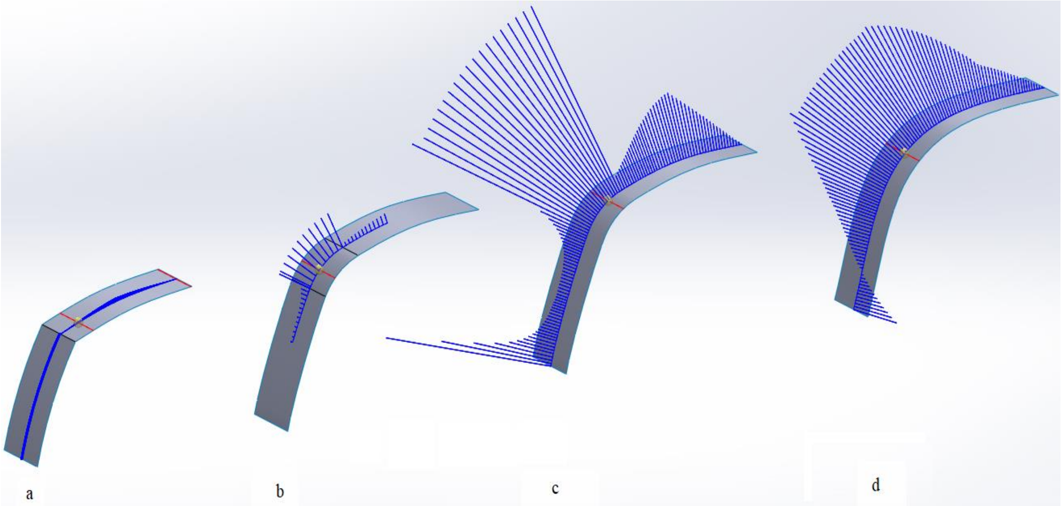


Fig. 2: Four different bounding surfaces; a) Regular Contact, b) Tangency, c) Tangency and Fit Spline, d) Curvature Continuity.

Deviation analysis
The deviation analysis tool allows users to evaluate the angle of faces along a common edge to understand the type of continuity between those faces. Fig. 3 illustrates how deviation analysis provides an insight to recognize the type of continuity between available surfaces.

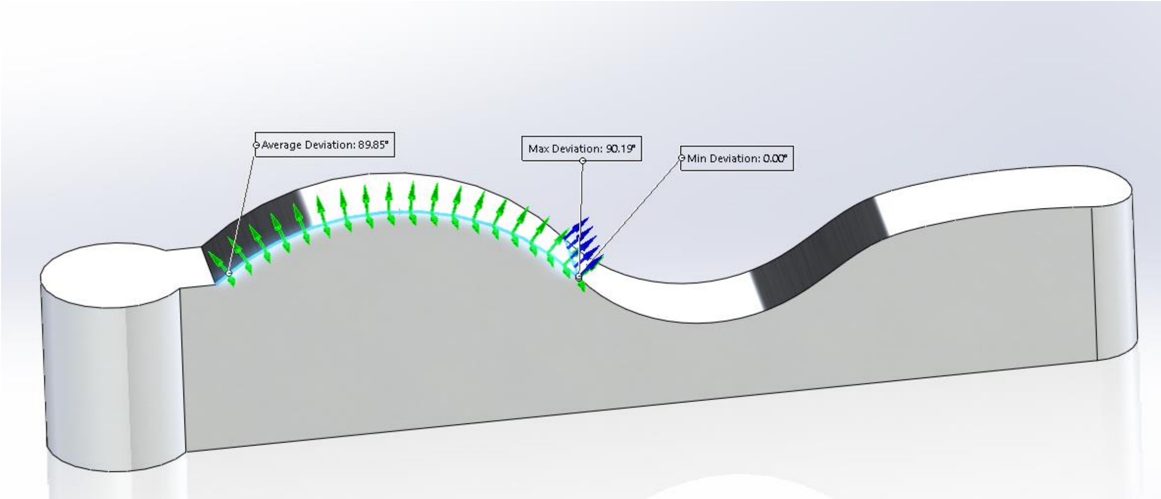


Fig. 3: Deviation analysis showing min, average and max deviation of the surface.

Curvature command
The curvature command is a qualitative color-coding approach in which faces are colored according to their curvature values as demonstrated in Fig. 4.

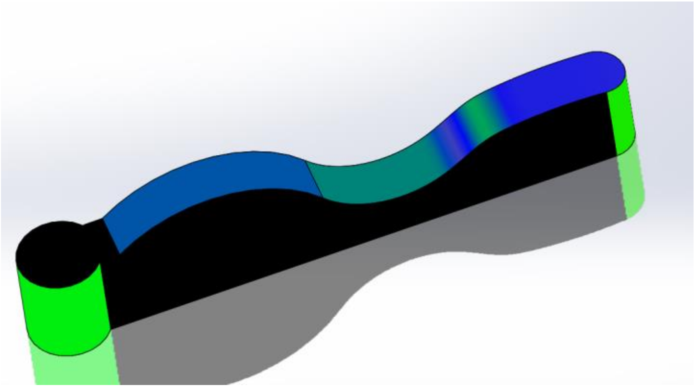


Fig. 4: Using curvature command tool to demonstrate faces' curvature values.

Zebra stripes tool

The zebra stripes tool determines the continuity type between faces, and it works by simulating stripes of light reflecting from a surface. It looks for irregularities in both the position and the direction of the stripes especially around edges as shown in Fig. 5. A contact is an obvious misalignment in the stripes between faces. A tangency is recognized when stripes will match at the boundary, but they will typically take off in another direction very abruptly. A curvature continuous is known as stripes match at the boundary. They may change direction across the edge very smoothly.

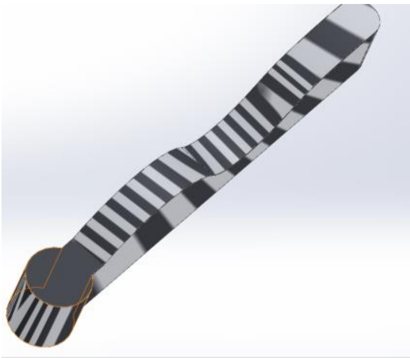


Fig. 5: Zebra stripes tool for determining the continuity type between faces.

SolidWorks provides some tools for geometry analysis as mentioned. However, additional quantified analyses, such as a curvature evaluation as shown in Fig. 6 is not performed. Another tool that will assist the designer is a surface smoothness analysis (Fig. 7). Rhino is used to develop these, and other related, advanced mold analyses.

Evaluating and modification of Surface features with Rhino

Curvature Analysis

Using a curvature analysis tool allows one to detect type of a curvature and quantify the curvature value on a surface. It also enables the designer to locate and correct unacceptably sudden changes like bumps, dents, flat areas, or ripples. As a part of this evaluation tool, Gaussian and Mean analyses show if and where there are anomalies in the curvature of a surface. Fig. 6 shows curvature analysis tool applied on a typical mold surface illustrating curvature value ranges from positive curvature (red, bowl-like) to zero (green, flat) to negative curvature (blue, saddle-like). It also generates maximum principal curvature, minimum principal curvature and Gaussian curvature values which are helpful in deciding if a surface can be developed into a flat pattern. Using a 'Mean curvature' value helps finding areas of abrupt change in the surface curvature so it can be corrected if needed.

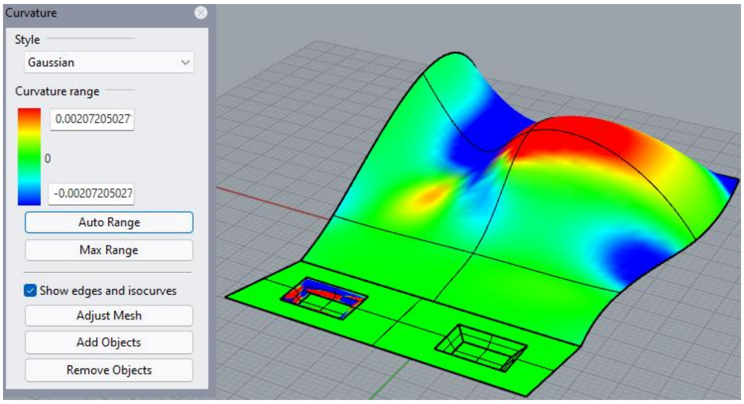


Fig. 6: Gaussian analysis for understanding saddle-like, bowl-like, and flat areas.

Surface flattening

When it comes to draping a fabric onto a sophisticated curvy mold, there are regions in the fabric where it will be more likely exposed to wrinkle and side over-draping out of the mold borders. Therefore, it is important to cut the fabric so that it fits the shape of the mold as it is draped over for a better conformity. Surface flattening tool in Rhino performs this, as shown in Fig. 7. This will be extended to develop origami inspired specialty grippers (Miura type folds), with living hinges [13].

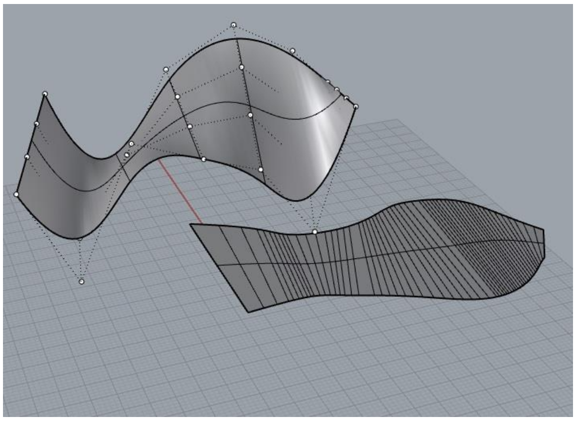


Fig. 7: Mold surface flattened representing the most suitable cut for the fabric.

Conclusion:

Mold geometry analysis tools via SolidWorks can be used to highlight potential problematic mold regions; however, additional analyses to quantify problematic regions need to be developed. Existing tools that can be used include curvature combs, and deviation analysis to determine types of bonding faces. New tools, such as developing a smoothing index, provides insights that will be able highlight fabric-mold interactions. The final goals are to predict and modify potential high probability wrinkle or draping regions of concern (which will be fabric and mold dependent), and to develop specialty grippers that can adapt to the fabric-mold interface. This will improve production throughput and product quality.

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