MULTI-OBJECTIVE OPTIMISATION OF WOVEN COMPOSITE DRAPING USING GENETIC ALGORITHMS

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SUMMARY

This paper presents a draping optimisation scheme based on the integration of a commercial kinematic drape simulation code and a genetic algorithm. The kinematic model allows a fast solution to the drape model which reproduces successfully the distribution of shear over the component surface, while a genetic algorithm drives the optimisation. Various setups of the problem are considered, including single and multiple objective solutions. The efficiency of the methodology is evaluated based on the results of the scheme applied to the draping of a composite pilot helmet.

1. INTRODUCTION

The draping of woven composites affects both the quality and the performance of composite components. Models that simulate draping are divided into two main categories. Kinematic models [1] which perform a mapping of the reinforcement to the manufacturing tool and assume inextensible tows that rotate freely at the crossover points. Pure shear is the only active deformation mechanism and computational times are very low. The second approach is based on the use of finite elements [2]. In these models the fabric is represented by an assembly of shell elements in contact with the rigid tool surface, while both material and geometric non-linearities are taken into account. Finite element models reproduce successfully mechanical effects at the expense of very high computational cost.

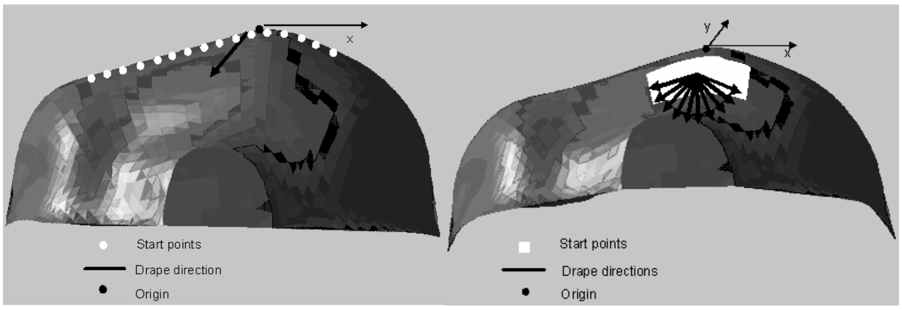
Drape modelling is currently used for process design and sensitivity analysis. Solution of the drape model for a limited number of drape setups is usually performed by varying manually the process parameters. The work presented here concerns the use of genetic algorithms (GAs) for automated optimisation. GAs are computationally expensive and, therefore, the use of a kinematic model for the solution of the drape problem is necessary. The Layup drape code of Simulayt Ltd implemented as a COM object [3] is used here with an efficient linkage to the GA. The optimisation scheme is applied to the design of the drape process so that objectives related to the shear deformation of the textile are optimised. The solution can then be imported as a Layup file into the MSC.Patran Laminate Modeler for visualisation and subsequent finite element analysis, utilising the as-draped fibre angles. The draping of a composite helmet is used to demonstrate the concepts and evaluate the scheme.

2. OPTIMISATION SCHEME AND IMPLEMENTATION

Genetic algorithms solve an optimisation problem by evolving a population of points in the search space of solutions (generation). They employ performance sensitive selection, crossover and mutation operations in order to reproduce a new population from the current population [5]. The members of the generation (individuals) are usually encoded in bit strings (chromosomes) and the algorithm is iterated until a convergence criterion is met. The conventional GA is well suited for optimisation problems in which a single-valued variable characterises the performance of a point in the design space. Most real world optimisation problems involve performance measures that cannot be described by a single criterion. In these cases, more than one optimisation objective has to be satisfied simultaneously and a number of optimum solutions may exist. The set of all solutions is the Pareto efficient set and comprises all points of the design space that cannot be improved with respect to one objective without worsening another objective (non-dominated points). The potential existence of a number of different solutions leads to the development of adaptations of the conventional GA. Multi-objective GAs use dominance, i.e. the fitness of an individual is an increasing function of the number of individuals it dominates, and employ sharing to maintain diversity, i.e. the fitness of an individual is a decreasing function of the number of individuals that are close to it [6, 7]. In addition, they maintain an archive of the Pareto set which is updated as the GA evolves. An algorithm, based on these principles was developed and implemented in C++. A C++ interface that allows the execution of the LayupCOM object [3] from the GA was also implemented. The algorithm starts with the generation of a random population of feasible solutions, which are encoded as binary strings. The fitness of the individuals is evaluated by testing each individual for dominance and proximity against all others. If an individual is dominated its fitness decreases by a specified amount. Similarly, if the points corresponding to two individuals in the objective space are within a sphere of predefined radius, their fitness decreases. Once the fitness of all individuals in the current generation has been evaluated, the population is sorted based on fitness. The best individuals are passed directly to the next generation (elitism). Subsequently, a pair of individuals is selected using a tournament procedure. The two selected individuals produce a new individual using uniform crossover. Each bit of the new individual takes the value of the corresponding bit of one of the parents which is selected randomly. The new individual goes through a mutation operation, which flips bits of the individual chromosome with a very low probability. Then, the individual is sent to the new population, and the selection, crossover and mutation sequence is repeated until all individuals required for the new generation are produced. The new population is tested for non-dominated individuals, which are sent to the Pareto set archive. The whole procedure is repeated until convergence.

The draping of a composite pilot helmet is used to demonstrate the applicability of the optimisation methodology. Two versions of the drape problem are considered; the first version corresponds to the full geometry in which symmetry constraints need to be met by potential solutions to the optimisation problem, the second version corresponds to one half of the geometry which is treated as an independent component without any symmetry. The latter is relevant to the case of draping the two halves of the pilot helmet separately. Figure 1.a illustrates the full helmet geometry. The design parameters included in the full helmet optimisation problems are the start point of the drape and the amount of pre-shear applied to the fabric.

Only one drape direction is considered, at an angle that always forces the bias direction of the fabric to align with the symmetry axis of the helmet. The case of the half helmet is illustrated in Figure 1.b. In addition to the drape starting point and pre-shear, the direction of drape is included as a design parameter in this case. The objectives of the optimisation are the minimisation of the maximum absolute shear angle and the minimisation of the average absolute shear angle. Two single-objective and one two-objective problems were considered for each of the geometries. The range of the design parameters and the parameters of the GA for the various optimisation problems are summarised in Table 1. It should be noted that the full helmet problems correspond to a search space with 512 design points in total. The lack of symmetry in the half helmet results in a much wider design space comprising 16,384 points.



(a) (b)

Figure 1:
Pilot helmet geometry and drape start point and directions: (a) Full helmet drape; (b) Half helmet drape.

	Full helmet drape		Half helmet drape	
	One objective	Two Objectives	One objective	Two Objectives
Start point x coordinate (cm)	-5.0 – 7.0	-5.0 – 7.0	-4.0 – 4.0	-4.0 – 4.0
Start point y coordinate (cm)	0.0 – 0.0	0.0 - 0.0	-9.0 – -5.0	-9.0 – -5.0
Drape direction(^{o})	45 – 45	45 – 45	0 – 180	0 –180
Pre-shear angle (^{o})	-22.5 – 24	-22.5 – 24	-22.5 – 24	-22.5 – 24
Population size	8	30	50	100
Elite size	1	3	5	15
Reproduction population size	6	25	35	75
Uniform crossover probability	0.5	0.5	0.5	0.5
Mutation probability	0.1	0.1	0.1	0.1
Pareto archive size	1	25	1	30
Binary string size	9	9	14	14

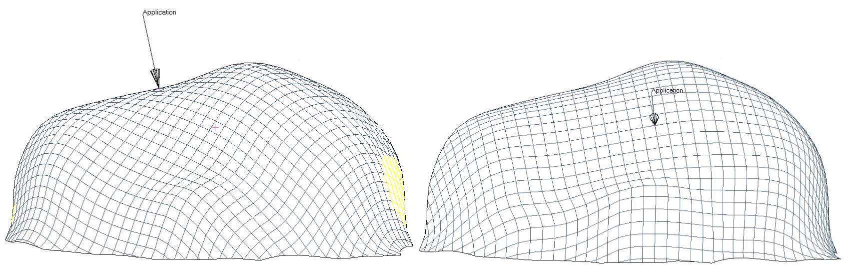
Table 1: Design space and parameters of the GA.

3. RESULTS AND DISCUSSION

The six optimisation problems were solved using exhaustive search over the design space to provide a basis for evaluation of the performance of the GA scheme. Table 2 summarises the results of exhaustive search for the 4 single-objective problems and Figure 2 illustrates the draped patterns of the solutions that minimise the maximum absolute shear angle for the two geometries. Figure 3 illustrates the set of feasible solutions and the non dominated sets for the two-objective problems.

	Full helmet drape		Half helmet drape	
	Maximum shear	Average shear	Maximum shear	Average shear
Start point coordinates (cm)	(-4.2, 0.0)	(-5.0, 0.0)	(-8.4, 0.6)	(-9.0, 0.6)
Drape direction(^{o})	63.0	44.2	96.0	96.0
Pre-shear angle (^{o})	18.0	1.5	0.8	0.8
Maximum absolute shear (^{o})	43.6	51.9	27.9	29.8
Average absolute shear (^{o})	15.5	9.8	7.7	6.8

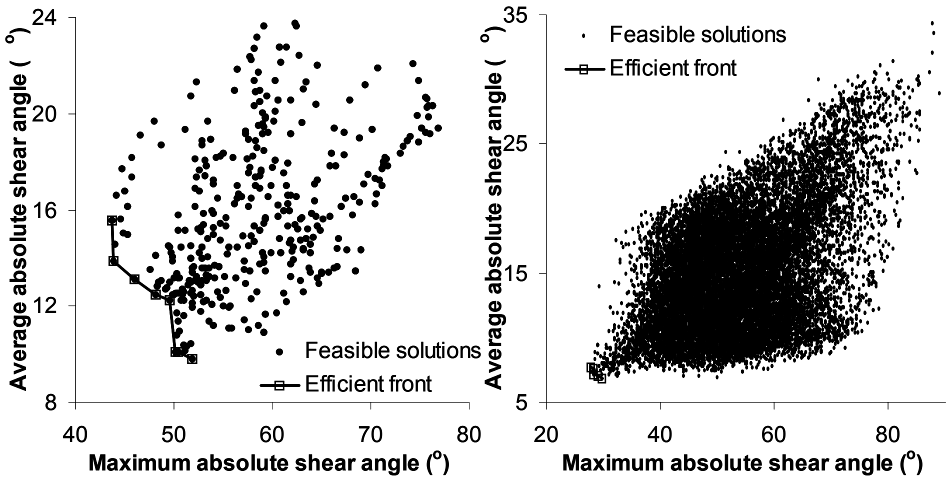
<u>Table 2:</u> Optimum solutions of the single-objective problems.



(a) (b)

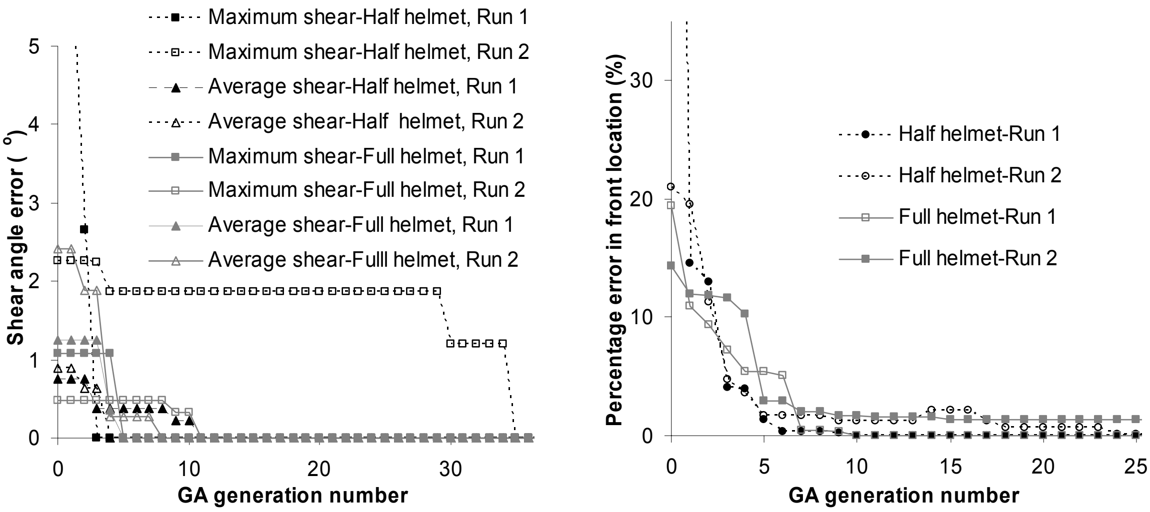
<u>Figure 2:</u>
Draped patterns of maximum shear minimisation solutions. (a) Full helmet drape; (b) Half helmet drape as viewed in the MSC.Patran Laminate Modeler.

The solutions of the single-objective problems for the full helmet geometry have starting points away from the apex (which is the natural choice for the start of drape). Maximum shear is minimised with the use of pre-shear, whereas the optimum solution with respect to average absolute shear is obtained with negligible pre-shear. The starting points of optimal drapes for the half helmet are located near the middle of the geometry. Both solutions involve negligible pre-shear. Overall, absolute shear angles are significantly lower than in the case of the full helmet geometry, indicating the benefits of draping the component in two stages. The Pareto efficient front comprises 9 points for the full helmet geometry and 5 points for the half helmet. Maximum shear and average shear appear to have positive correlation, especially in the half helmet geometry, which justifies the small size of the Pareto set.



(a) (b)

Figure 3:
Feasible solutions and efficient front of the two-objective optimisation problems.



(a) (b)

Figure 4:
Convergence of the genetic algorithm. (a) Single-objective optimisation problems; (b) Two objective optimisation problems.

The convergence of the runs of the GA for the single-objective problems is illustrated in Figure 4. The number of generations required to solve the full helmet problems ranges from 5 to 11 generations, which corresponds to 40 to 88 model runs or 8% to 17% of the computational effort required for the exhaustive search. Convergence of the GA for the half helmet geometry occurs within 3 to 35 generations which amounts to 150 to 1750 model executions or 1% to 10% of the computational effort required for the exhaustive search. Convergence results in the case of the two-objective problems are illustrated in Figure 4. The GA locates the non-dominated set within 5 to 11 generations. The computational effort required is approximately 30% of the exhaustive search in the full helmet optimisation and 3% of the exhaustive search in the half helmet optimisation. In general, the GA is relatively more efficient in the case of the half helmet. The difference between the two geometries is attributed to the large population of the half helmet case that allows operation of the GA in a more efficient regime.

4. CONCLUSIONS

Successful integration of a commercially available drape code with a genetic algorithm allowed the optimisation of woven material draping with respect to manufacturing parameters such as the start point and direction of the drape and the amount of fabric pre-shear. Single or multiple objective problems can be treated successfully using this scheme. The GA allows significant reduction of computational times, as solution requires 1% to 30% of the computational effort required for an exhaustive search. The GA operates in its highest strength when the process optimisation problem corresponds to a wide design space. In addition, the seamless integration of a drape code with the GA allows robust and automated design of the drape process.

5. ACKNOWLEDGEMENTS

The support of the following, via the DOTComp project [8] is gratefully acknowledged: EPSRC, ESI Software SA, Ford Motor Company Ltd., Granta Design Ltd, Hexcel Composites, MSC.Software Ltd, University of Nottingham, Polynorm Plastics (UK) Ltd, Saint-Gobain Vetrotex International SAS, the UK Ministry of Defence.

REFERENCES

[1] F. Trochu, A. Hammami and Y. Benoit, Compos. Part A-Appl. S., 27 (1996), 319.
[2] A. K. Picket, T. Queckborner, P. De Luca and E. Haug, Compos Manuf., 6 (1995), 237.
[3] LayupCOM Interface Specification, Simulayt Limited, UK.
[4] MSC Software Documentation, MSC.Laminate Modeler User's Guide, MSC Software Corporation, USA.
[5] M. Mitchell, An introduction to genetic algorithms, MIT Press, USA, 1998.
[6] E. Zitzler, L. Thiele, M. Laumans, C. M. Fonseca and V. G. da Fonseca, IEEE T. Evolut. Comput. 7 (2003), 117.
[7] N. Srinivas and K. Deb, J. Evolut. Comput., 2 (1994), 221.
[8] EPSRC Grant, Design Optimisation of Textile Composite Structures (DotComp), Reference: GR/S67098/01.