OPTIMIZATION IN REDUCING THE ROLLING RESISTANCE OF THE TWEEL AND THE DESIGN OF META-MATERIALS

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- OUTLINE:
  - INTRODUCTION TO ROLLING RESISTANCE
  - SCOPE OF THE PROJECT
  - OPTIMIZATION IN DESIGNING THE TWEEL
  - RESULTS AND CONCLUSIONS
  - FUTURE WORK

➢ INTRODUCTION TO ROLLING RESISTANCE:

• Rolling resistance occurs when a rotating tire comes in contact with the ground. This is caused by the deformation of the tire, contact surface, or both.

• It is the force required to keep the tire moving at a uniform speed. Lower the rolling resistance, less is the energy required to keep the tire moving.

• Rolling resistance significantly depends on the material of the tire and the sort of ground.

• The primary cause of rolling resistance is the Hysteresis loss, which is a characteristic of a material such that the energy of deformation is more than the energy of recovery.

➢ SCOPE OF THE PROJECT:

- Reduce the rolling resistance of the Tweel by fifty percent. And this implies that , instead of using hyperelastic materials, we may have to use materials that exhibit low hysteresis loss and at the same time mimic the desirable properties of a hyperelastic material.

- This leads to the concept of Meta-Materials.

- Four problems were defined to determine the requirement list for the design of Meta-material through the analysis approach.

1	ISOTROPIC BILAYERED SHEAR MODULE
2	ISOTROPIC POLYLAYERED SHEAR MODULE
3	ORTHOTROPIC BILAYERED SHEAR MODULE
4	ISOTROPIC BILAYERED SHEAR MODULE WITH ORTHOTROPIC MEMBRANE MODULII

- Focus is on designing low hysteresis loss shear beam. The material and geometric properties of spokes remain the same throughout

OPTIMIZATION IN DESIGNING THE TWEEL:

Definition of problem-1:

- Objective: Minimize the difference in shear strain
- Subject to: -Uniform contact pressure over the contact patch region.
  -Average contact pressure lies between 30 psi and 60 psi.

VARIABLE	BOUNDS	UNITS
INNER INEXTENSIBLE MEMBRANE- YOUNG'S MODULUS	1000-210000	Mpa
INNER INEXTENSIBLE MEMBRANE- POISSON'S RATIO	0.01-0.49	-
INNER INEXTENSIBLE MEMBRANE- THICKNESS	1.00-2.00	mm
OUTER INEXTENSIBLE MEMBRANE- YOUNG'S MODULUS	1000-210000	Mpa
OUTER INEXTENSIBLE MEMBRANE- POISSON'S RATIO	0.01-0.49	-
OUTER INEXTENSIBLE MEMBRANE- THICKNESS	1.00-2.00	mm
SHEAR LAYER: RIGIDITY MODULUS	0.20-20.00	Mpa
SHEAR LAYER: HEIGHT	7.00-15.00	mm

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➢ OPTIMIZATION IN DESIGNING THE TWEEL:

- Optimization is carried out using the 2D-Tweel Abaqus simulation model in ModeFrontier.
- ModeFrontier is a multi-objective optimization and design environment.
- Simplex algorithm, which is well suited for single objective problems is used to optimize.
- Two approaches were considered to find the optimal solution:

  a. Develop the response surface models with respect to average contact pressure and difference in shear strain using Design of Experiments.

  b. Use the Abaqus simulation model and find the optimal.

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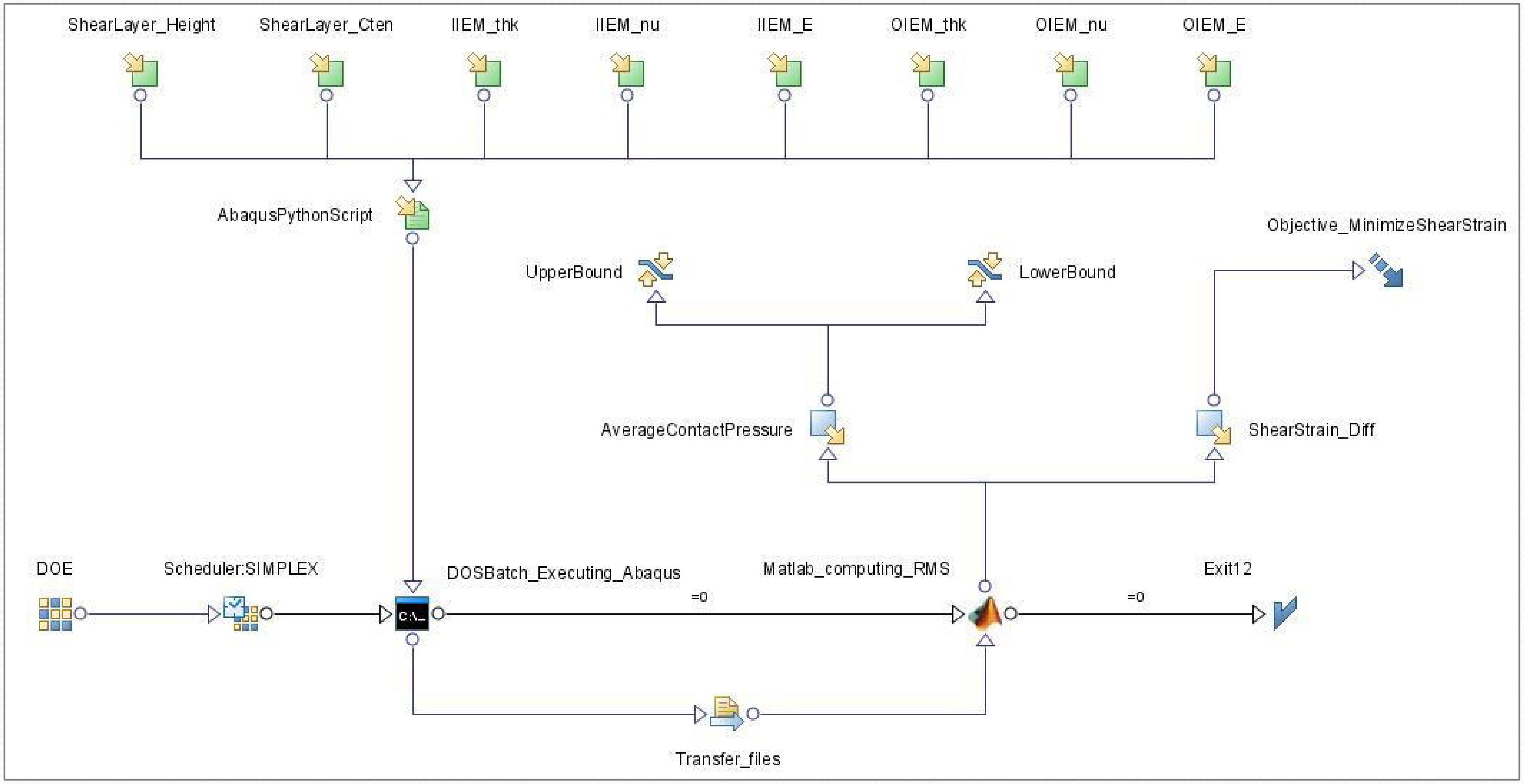
➢ MODEFRONTIER WORKFLOW:



➢ Results from problem-1:

IIEM_E (Mpa)	5322.16	NOT STIFF ENOUGH
IIEM_nu	0.30	
IIEM_thk (mm)	1.62	
OIEM_E (Mpa)	3255.85	NOT STIFF ENOUGH
OIEM_nu	0.03	
OIEM_thk (mm)	1.50	
Shear_Modulus (Mpa)	20.00	
ShearLayer_Height (mm)	13.33	
AverageContactPressure (Mpa)	0.33	
ShearStrain_Diff	0.01	

- Number of feasible designs are obtained.
- But, the material with these properties for IIEM and OIEM doesn't exist.
- This leads to case-2 of problem-1.

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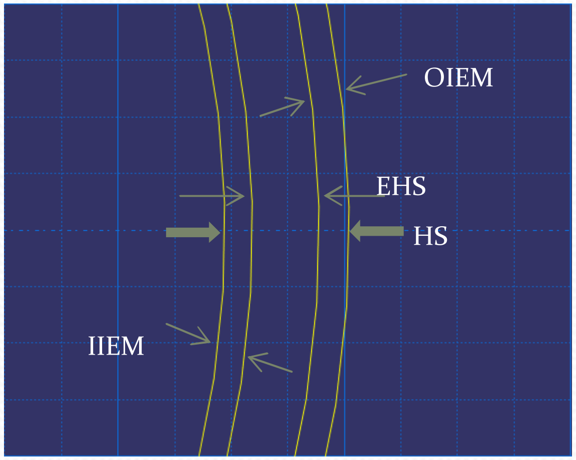
➢ Case-2 with four variables:

- Considering the desired properties of IIEM and OIEM, we can assume that they are made of Steel. So, the number of variables is reduced to four.

IIEM_thk (mm)	2.26
OIEM_thk (mm)	1.78
Shear_Modulus (Mpa)	18.80
ShearLayer_Height (mm)	8.50
AverageContactPressure (Mpa)	0.41
ShearStrain_Diff	0.03



- The effective height to accommodate meta-material in this case would be 4.5mm. This would be a challenge if the manufacturability aspect is considered.

➢ Case-3: Single Variable (c10) Optimization Results:

	HEIGHT_SHEAR LAYER (mm)	IIEM_THICKNESS (mm)	OIEM_THICKNESS (mm)	EFFECTIVE_HEIGHT_FOR_ META-MATERIAL (mm)	C10_SHEAR LAYER	SHEAR_MODULUS (Mpa)	AVERAGE_CONTACT_ PRESSURE (Mpa)
CASE-1	12	1	1	10	4.44	8.88	0.4136
CASE-2	13	1	1	11	4.03	8.06	0.4136
CASE-3	14	1	1	12	3.7	7.4	0.4136
CASE-4	14	2	2	10	4.43	8.86	0.4136
CASE-5	15	1	1	13	3.4	6.8	0.4136
CASE-6	15	2	2	11	4.01	8.02	0.4

- All the above solutions are feasible. But, the ultimate challenge would be to design a Meta-material using a low hysteresis loss material that has an effective shear modulus and dimensions given in the table.

- Chris and Dr. Ju are working on Topology Optimization and Analytical study of regular and auxetic honeycomb structures respectively.

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- Future work:

  - Narrow down the design space of material properties for OIEM and IIEM, and perform the optimization rather than fixing them to be Steel (an initial assumption).

  - Finalize an Optimal design for Tweel from Problem-1.

  - Continue working on remaining problems and provide Top-level Optimization results for Topology Optimization.

Thank you