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MATERIAL COMBINATION RATIO OPTIMIZATION FOR PAVER BLOCK COMPOSED OF WASTE PLASTIC AND WASTE FOUNDRY SAND

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ABSTRACT

This research provides a quantitative methodology for determining the material combination ratio of paver blocks with highest possible compressive strength. The paver blocks considered are made with the combination of waste foundry sand and recyclable plastic mainly consisting of HDPE (High Density Poly Ethylene) plastic. Various combination ratios of the two materials are evaluated. The methodology is defined to perform the static structural and transient structural analysis with ANSYS Workbench 2023, combined with experimental tests. The numerical results such as deformations, stresses and strains are obtained with considerations of the desired loadings applying on the block. The optimal combination in ratio of sand and plastic is then determined to achieve the highest possible compressive strength of the block. The investigation of this research will provide a guidance to the researchers and engineers in quantitatively determining for the maximum strength of paver blocks composed of different materials desired.

Keywords: FEA, Paver Block, environmental-friendly process, recyclable materials.

INTRODUCTION

Paver blocks are widely used construction materials and exhibit superior performance. Notably, zigzag-patterned paver blocks demonstrate enhanced performance. This research studies the zigzag-patterned paver block known as Sand Plastic Waste (SPW) paver block that is composed of High Density Poly Ethylene (HDPE) waste plastic and waste foundry sand to reduce costs and contribute to environmental sustainability.

Arsod and Mr. N. D. (2019) in their paper Experimental Investigation on Concrete Paver Block and Plastic Paver Block has mentioned about the types of Paver Blocks designed according to the traffic flow.

This research aims to establish an approach including environmental conservation through the utilization of waste materials, increased strength in plastic-paved blocks compared to their concrete counterparts, providing numerous design possibilities, the provision of an economical construction material, cost-effectiveness compared to concrete paver blocks, the utilization of various waste materials in construction, and straightforward installation procedures.

MATERIAL ACQUISITION AND PROCEDURE OF MAKING THE SPW PAVER BLOCK

Scrap plastic wastes (SPW) were obtained from the local municipality landfill site in Anand, India, and subsequently transported to the Rhino Machines Factory. At the factory, the waste material underwent a thorough washing and sanitization process before utilization.

The density of SPW was determined to be 1660 kg/m3 following ASTMD792 testing procedures. PET plastic waste underwent a drying process for three days, followed by shredding, resulting in a powder-like form.

The foundry sand utilized in the manufacturing process was sourced from a customer industry supplied with manufacturing equipment by Rhino Machines. This foundry sand used here is a discarded waste product from a steel company, this foundry sand is the burnt foundry sand discarded after the casting process at the steel company has particle sizes ranging from 0.01 mm to 2 mm according to ASTM (D1140-17).

Various mix designs were employed for the SPW brick samples in this study, with percentages by dry mass of the foundry sand. Trial mix-design bricks were produced with different densities, using ratios of 90%:10%, 85%:15%, 80%: 20%, and 75%:25% of the dry mass of foundry sand and plastic waste. For ease of identification, the specimens were labeled SPW-I (75%:25%), SPW-II (80%:20%), SPW-III (85%:15%), and SPW-IV (90%:10%).

LOAD ANALYSIS

When the physical model was tested at a laboratory for compression test, the SPW Paver block was spreading and not breaking like a concrete paver block. Table shows the loads and time of loading application. Also, since the testing was done for a single block, it did not have testing condition as of real life. In case of actual application where the block is surrounded by similar blocks and no room for spreading under load, this phenomenon needs to be tested to find the mechanical properties and conditions of the block at 733500N force application.

Table 1 Loading Chart

Steps	Time [s]	Force [N]
1	0.	= 0.
	1.	0.
2	2.	= 40750
3	3.	= 81500
4	4.	= 1.2225e+005
5	5.	= 1.63e+005
6	6.	= 2.0375e+005
7	7.	= 2.445e+005
8	8.	= 2.8525e+005
9	9.	= 3.26e+005
10	10.	= 3.6675e+005
11	11.	= 4.075e+005
12	12.	= 4.4825e+005
13	13.	= 4.89e+005
14	14.	= 5.2975e+005
15	15.	= 5.705e+005
16	16.	= 6.1125e+005
17	17.	= 6.52e+005
18	18.	= 6.9275e+005
19	19.	7.335e+005
20	20.	0.

The force applied during the simulation is exactly the same as that applied during the laboratory testing, so that it is easier to compare the simulation and experimental values.

When the paver block was performed for compressive tests, the block deformed and spread into a disc type shape showing elasticity property rather than breaking like a concrete paver block. Hence, the simulation is performed to simulate real life conditions.

FINITE ELEMENT ANALYSIS – TRANSIENT STRUCTURAL ANALYSIS

Finite Element Analysis – Transient Structural Analysis

The numerical simulation of FEA is performed on ANSYS Workbench 2023 four combination ratios, which would be the major combination ratios in which the paver blocks would be manufactured. The main objective is to find the deformation in each case and their mechanical properties. The material used for the research is waste foundry sand and plastic, and the final material is the combination of these two. Table 2 represents the material property of sand; Table 3 represents the material property of plastic HDPE and Table 4 represents the material property of the mixed material.

Table 2: Material Properties SAND

Density	2.64E-06	kg/mm³
Structural		
Young's Modulus	59.42	MPa
Poisson's Ratio	0.25	
Bulk Modulus	39.613	MPa
Shear Modulus	23.768	MPa

Table 3: Material Properties HDPE

Density	**9.59E-07**	**kg/mm³**
Young's Modulus	1080	MPa
Poisson's Ratio	0.4183	
Bulk Modulus	2203.2	MPa
Shear Modulus	380.74	MPa
Isotropic Secant Coefficient of Thermal Expansion	1.45E-04	1/°C
Tensile Ultimate Strength	28.39	MPa
Tensile Yield Strength	28.39	MPa

Table 4: Material Combination Properties

Isotropic Elasticity	10-90 Ratio **(SPW IV)**		15-85 Ratio **(SPW III)**		20-80 Ratio **(SPW II)**		25-75 Ratio **(SPW I)**	
Derive from	Young's Modulus and Poisson's Ratio		Young's Modulus and Poisson's Ratio		Young's Modulus and Poisson's Ratio		Young's Modulus and Poisson's Ratio	
Young's Modulus	161.48	MPa	212.51	MPa	263.54	MPa	314.57	MPa
Poisson's Ratio	0.26683		0.27525		0.28366		0.29208	
Bulk Modulus	115.42	MPa	157.58	MPa	203.03	MPa	252.15	MPa
Shear Modulus	63.733	MPa	83.32	MPa	102.65	MPa	121.73	MPa
Isotropic Secant Coefficient of Thermal Expansion		1/°C		1/°C		1/°C		1/°C

The properties for fixed support and loading conditions is shown in Table 5. The load applied is distributed load.

Table 5: Boundary conditions and loading applied

Object Name	*Fixed Support*	*Displacement*	*Force*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Geometry	1 Face	16 Faces	18 Faces
Definition			
Type	Fixed Support	Displacement	Force
Suppressed	No		
Define By		Components	Vector
Coordinate System		Global Coordinate System	

X Component		0. mm (ramped)	
Y Component		Free	
Z Component		0. mm (ramped)	
Applied By			Surface Effect
Magnitude			Tabular Data
Direction			Defined

For transient analysis, we will have to setup the analysis settings for time and step. As illustrated in Table 6. The analysis is performed of 1 sec time step for 20 seconds with 20 total number of steps.

Table 6: Analysis Settings for transient analysis

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	20.
Current Step Number	19.
Step End Time	19. s
Auto Time Stepping	Off
Define By	Time
Time Step	1. s

As shown in Figure 1, the force is applied on the model. As we can see in the figure, the load increases gradually to reach 733500N at the 19th sec time step. Due to the gradual increase in load, we are able to analysis the impact and deformation in the paver block over the time. This methodology is applied to all the four scenarios we considered for the analysis. We will now discuss the results of these analyses for all the four combination ratios in detail in the next part.

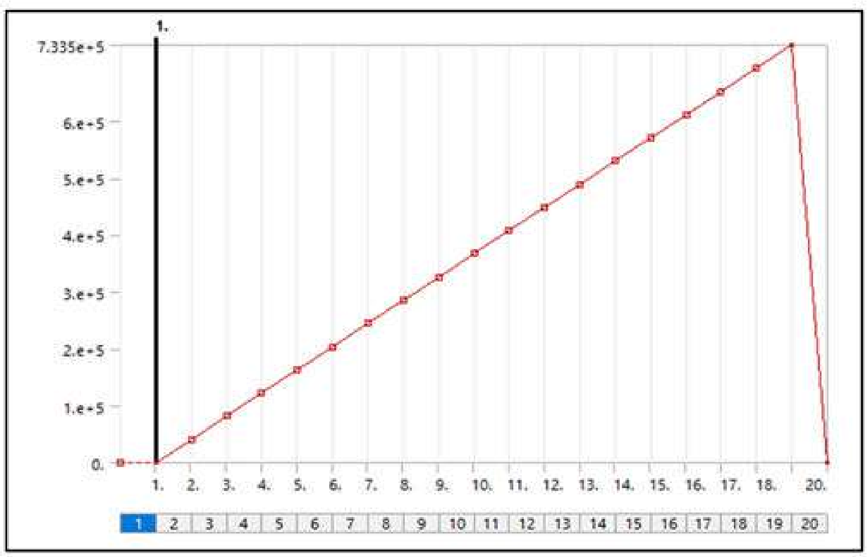

Figure 1 Graph of Loading

RESULTS AND DISCUSSION

Table 7 illustrates the total deformation and stress on SPW I under transient loading condition. The results show that the deformation is 3.7796 mm at the maximum load condition of 733500N, and the maximum stress produced is 51.827 MPa which is way less than the material's maximum ability to handle stress. This means the block is capable of handling more load on the surface. This is the transient analysis hence the maximum deformation and maximum stress are during the 19th sec respectively.

Table 7: Summary of FEA result of SPW 1

Object Name	*Total Deformation*	*Equivalent Stress*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Total Deformation	Equivalent (von-Mises) Stress
By	Time	
Display Time	19. s	
Separate Data by Entity	No	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Results		
Minimum	0. mm	9.2744 MPa
Maximum	3.7796 mm	51.827 MPa
Average	3.0647 mm	19.935 MPa
Minimum Occurs On	Block-FreeParts	
Maximum Occurs On	Block-FreeParts	
Minimum Value Over Time		
Minimum	0. mm	0. MPa
Maximum	0. mm	9.2744 MPa
Maximum Value Over Time		
Minimum	0. mm	0. MPa
Maximum	3.7796 mm	51.827 MPa
Information		
Time	19. s	
Load Step	19	
Substep	1	
Iteration Number	65	
Integration Point Results		
Display Option		Averaged
Average Across Bodies		No

Figures 2 and 3 show the maximum deformation of the SPW I paver block under transient loading conditions. The deformation is maximum at the edges of the paver block where there is a 45˚ bend in the design of the block. Figure 4 is the graphical representation of deformation in the block with respect to load application over period of time. As the force is maximum at 19 sec, the result also shows the max deformation of 3.7796 mm at the peak force of 733500N at the 19th sec.

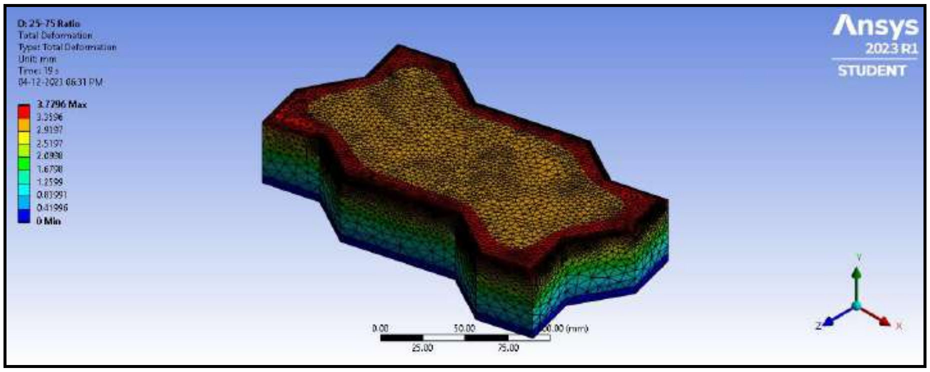

Figure 2: SPW I - Total Deformation

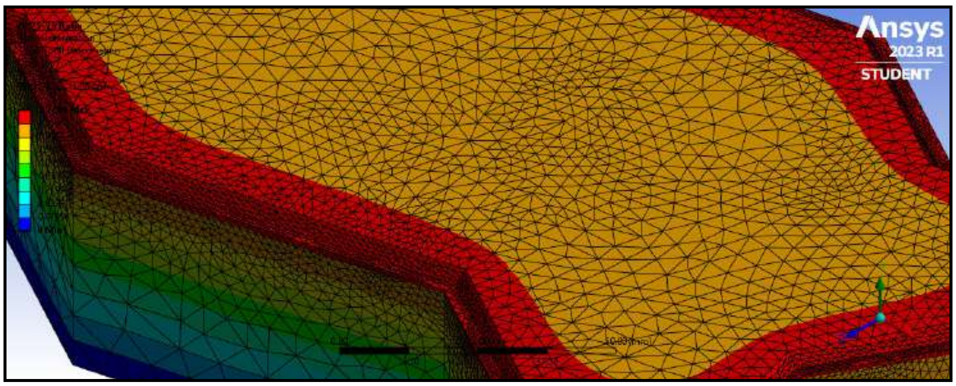

Figure 3: SPW I - Section with Maximum Deformation

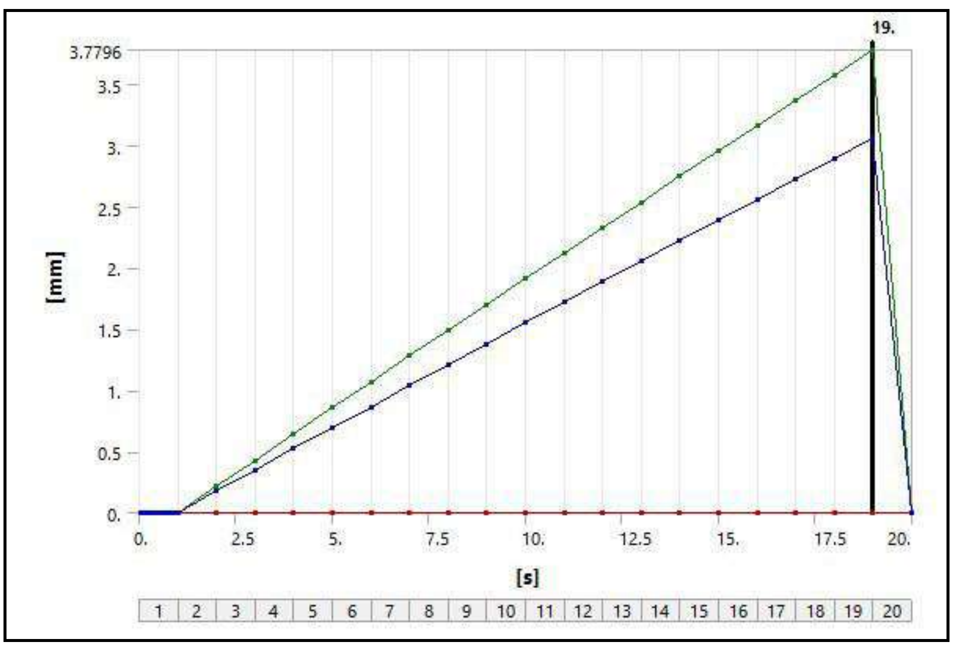

Figure 4: SPW I - Graph of Total Deformation

Figures 5 and 6 show the von-misses stress on the SPW I. The figure shows the stress distribution on the paver block which is maximum at the edges, the detailed stress is shown in figure 20 which shows the section that endures most stress.

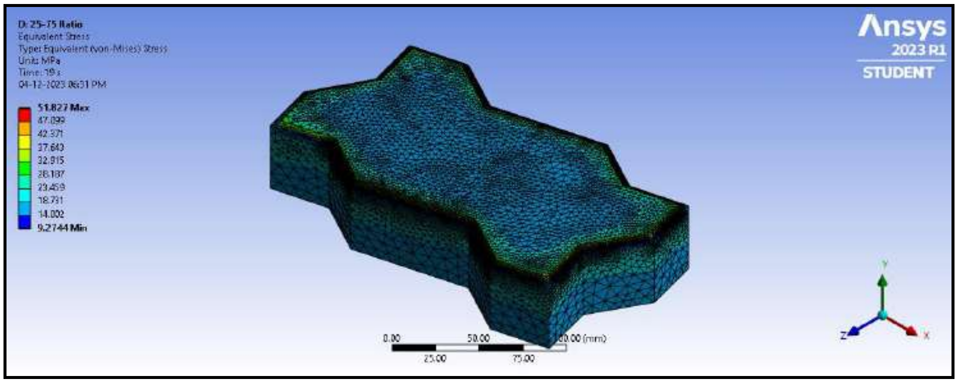

Figure 5: SPW I - Stress Distribution

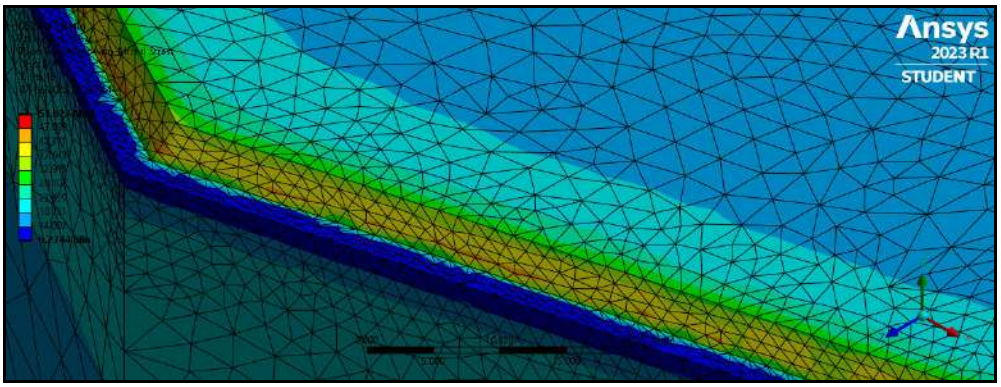

Figure 6: SPW I- Section enduring Maximum Stress

As mentioned earlier, the significant thing checked here is if the meshing results obtained are within the acceptable range or not. The table below shows the convergence summary of the analysis. The allowable change between the two iterations comes to be around 0.274%, which is within the acceptable range of 10%. Hence, this verifies that the results obtained from this analysis is accurate and within the acceptable limit. The graph below shows the convergence discussed here.

Table 8: Convergence Summary for SPW1

Object Name	*Convergence*
State	Solved
Definition	
Type	Maximum
Allowable Change	10. %
Results	
Last Change	0.27387 %
Converged	Yes

The investigations are also conducted for the blocks with the other different material combination ratios. Table 9 below lists the equivalent stresses and total deformations for all types of paver blocks SPW I, SPW II, SPW III and SPW IV in comparison with that of the conventional concrete.

As can be seen from Table 9, the equivalent stress of the paver blocks composed of waste plastics and foundry sand are much higher than that of the concrete block. The deformations of the plastic-sand paver blocks are also higher than that of the concrete block.

Table 9: Result Comparison of Paver Blocks

Results	Equivalent Stress (MPa)	Total Deformation (Y direction) (mm)
Concrete	41.055	0.0773
25-75 Ratio	51.827	3.7796
20-80 Ratio	53.149	4.5762
15-85 Ratio	56.002	5.7434
10-90 Ratio	50.614	7.6151

SIGNIFICANCE OF DEFORMATION IN INDUSTRIAL USE

While the 15-85 ratio block exhibits higher deformation, it is crucial to understand whether this deformation is within acceptable limits for the intended application. In many real-world scenarios, slight deformations are tolerated, especially when balanced with other desirable properties such as sustainability, cost-effectiveness, and ease of production.

When we compare the loading chart to the deformation in the paver block in Table 10, we can see that for applications like playgrounds, driveways, walkways where the load application will be less than 40750 N i.e, 4154 kg at an instant over 95% of its lifetime and the deformation corresponding to it is 0.33012 mm, which is almost negligible.

Table 10: Force vs. Deformation Comparison

Time	Force (N)	Deformation Maximum (mm)
1	0	0
2	40750	0.33012
3	81500	0.6586
4	122250	0.98549
5	163000	1.3108
6	203750	1.6347
7	244500	1.9571
8	285250	2.2782
9	326000	2.5979
10	366750	2.9164
11	407500	3.2337
12	448250	3.551
13	489000	3.8664
14	529750	4.1809
15	570500	4.4946
16	611250	4.8075
17	652000	5.1199
18	692750	5.4318
19	7.34E+05	5.7434
20	0	6.08E-03

CONCLUSION

In conclusion, this research has delved into the realm of sustainable construction materials by investigating the optimal mixture content ratio for paver blocks composed of waste foundry sand and HDPE plastic. The objective is to discern the mechanical properties of these novel mixtures, specifically focusing on stress and deformation values, and to draw meaningful comparisons with traditional concrete blocks.

The results obtained from the experimentation offer valuable insights into the performance of the different compositions. The reference point, pure concrete, exhibits an equivalent stress of 41.055 MPa and a total deformation of 0.0773 mm. This baseline data provides a crucial context for evaluating the effectiveness of the mixtures incorporating foundry sand and HDPE plastic.

Comparing the results to the baseline concrete blocks, it is evident that the mixtures incorporating foundry sand and HDPE plastic exhibit higher equivalent stress values, signifying improved stress resistance. This enhancement comes at the expense of increased total deformation. However, the deformation leads to absorption of energy and therefore may find suitable applications in the areas such as playground.

Additionally, this research contributes valuable knowledge to the construction materials field by shedding light on the performance of paver block mixtures with waste foundry sand and HDPE plastic. The findings pave the way for further exploration into sustainable and resilient construction practices, offering a potential avenue for reducing the environmental impact of conventional materials while meeting the structural demands of modern construction research.

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