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Comparative Study of Hyper Elastic Material Models

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Abstract

Hyper elasticity refers to a constitutive response that is derivable from free elastic potential energy. Hyper elastic materials are widely used in different fields due to its unique Stress-Strain relationship and independent strain rate. Rubber is the common example for this kind of material and is most widely used due to their advantages like high elasticity, resistance, breaking strength, good wear, elongation, etc. In structural engineering, Hyper elastic material, rubber have been used in dampers, conveyor belts, vibration isolation bearings or shock absorbers and impact absorbers. An increase of applications requires a better understanding of the mechanical behaviour of rubber-like materials, it is necessary to develop a basic understanding of the various hyper elastic models using ANSYS. It is the best software used for the modelling of large deformations and provides a means of modelling the Stress-Strain behaviour of such materials. The objective of present project is to study the Strain energy functions for various models and the various parameters of each model with different displacements values and to check the Stress Strain relations obtained from each model by using ANSYS 16.2. This work is to be carried for two types of cases, first case is the comparison of Two plates one is with a single central circular hole and the other is single central circular hole with two adjacent holes with one end fixed and the second case is the Dog-bone geometry.

Keywords: Hyper elasticity 1, ANSYS 2.

INTRODUCTION

The applications of hyper elastic rubber-like materials in different industrial areas were increased. In engineering fields, rubbers have been used in dampers, conveyor belts, vibration isolation bearings or shock absorbers and impact absorbers whereas in aerospace industry rubber rings are used in fuel systems. In hyper elastic materials lesser stresses are developed for any amount of strains compared to a linear elastic material. Therefore, hyper elastic materials are able to take much larger strains without significant in stress. Thus, these plates are compared with different displacements and with different size of circle diameter with the change of model parameters.

G.Marckmann and E.Verron [1] studied all material parameters and the stretch range of validity of each model available in ANSYS and proposed a thorough comparison of twenty hyper elastic models for rubber-like materials and were ranked based on the greater is the number of material parameters and larger is the validity range of a model. Kurt Miller [2] studied the input requirements of mathematical material models that exist in structural, non-linear and the incompressible attributes of elastomers by the multiple strian states testings. Prashant Nimbalkar et al., [3] studied 3, 5 & 9 parameter models in ANSYS were used by taking inputs from experimental stress-strain data and performed a finite element analysis on a hyper elastic Mooney-Rivlin material model and applied it to the air intake system and Uni-axial test in ANSYS were performed and curve fitting was carried out. Tie Hu and Jaydev P. Desai [4] studied D/A ratio upon stress concentration factor for different cases with different mesh element size and loads to see how part geometry can influence the maximum stress at critical points for a rectangular plate with a large hole in the centre and changing the adjacent small hole diameters to see the effects on the magnitude of the maximum stress and how this influences the stress concentration factor. Vishal Nayyar et al., [5] studied Stress concentration factor, Finite element analysis to calculate stress concentration around a circular hole in the composite plate under longitudinal tensile load.

The primary scope is to compare stress from non-linear models by using ANSYS 16.2. The comparison is done by varying displacement, hole diameter and thickness of the plate. The secondary scope is to compare stresses with coefficients of different models by using ANSYS 16.2.

METHODOLOGY

Comparison of non linear hyper elastic material models available in ANSYS for two different type of cases, first case is The Comparison of Two plates with a central single circular hole and a central circular hole with two adjacent holes and the second case is with the Dog-bone geometry.

CASE 1, A plate of size 1000*1000*10mm is one plate with central circular hole and another plate with central circular hole with two adjacent holes (adjacent hole diameter, 50mm). The initial diameter of the central circular hole is 100mm and is then increased in steps of 200, 300mm by keeping dimensions of the plate fixed. The plate is fixed with all degrees of freedom at one end and other end is subjected to displacements in x direction with displacement 500mm. Considering Plane 182 elements (4-noded quadrilateral) that deals with plane stress and plane strain, the material properties of an hyper elastic rubber like material is obtained from experimental (stress-strain) data from Prashant Nimbalkar et al., [3] and is used to evaluate the hyper elastic material models (Mooney-Rivlin(2,3,5parameters), Neo-Hookean, Ogden) with the mesh element tool size 3 as given in ANSYS 16.2. The value of maximum stress in x-direction and deflection of a plate is determined and from time hysteresis analysis a Stress-Strain graph will be obtained. Effect of the geometry by the stress distribution around the hole is studied.

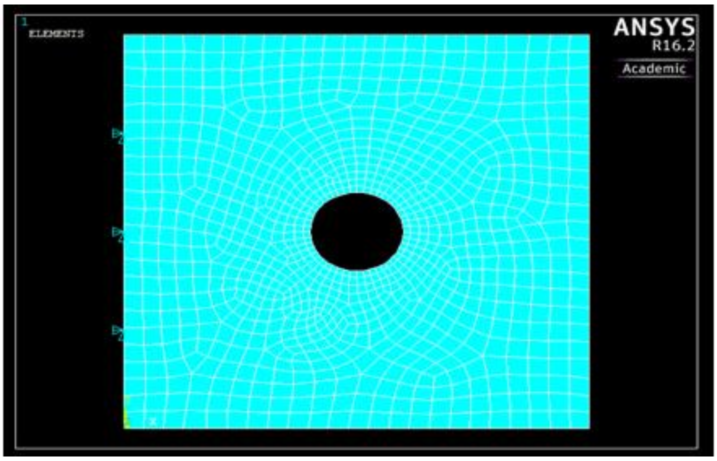

Figure 1: Mesh plate with a circular hole at the centre

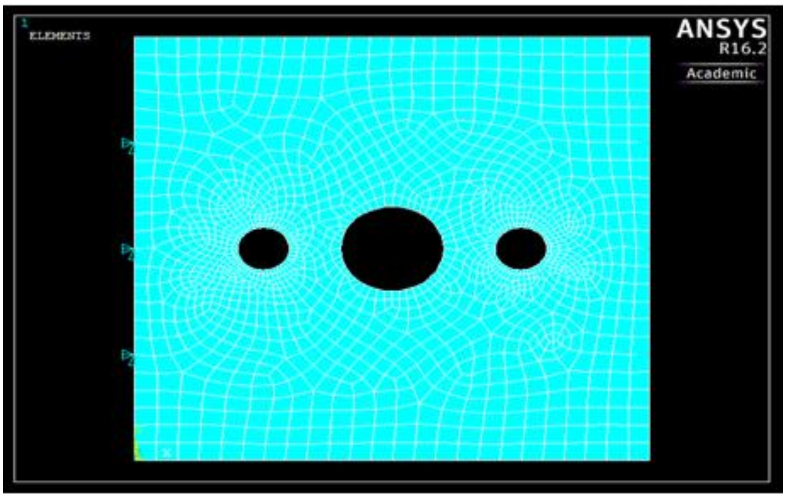

Figure 2: Mesh plate with central circular hole with two adjacent holes

CASE 2, A Dog-bone plate with uniform thickness of 6mm as shown in figure 3 below (all dimensions are in mm), one end is fixed with all degrees of freedom and other end is subjected to displacements in X direction and its adjacent sides were fixed in Y direction, initial displacement is 10% and is then increased in steps up to 90%. Considering a Plane 182 element (4-noded quadrilateral) that deals with plane stress and plane strain, the material properties of an hyper elastic rubber like material is obtained from experimental (stress-strain) data from Prashant Nimbalkar et al., [3] and is used to evaluate the hyper elastic material models (Mooney-Rivlin (2, 3, 5parameters), Neo-Hookean, Ogden) with the mesh element tool size 3 as given in ANSYS 16.2. The value of maximum stress in x-direction and deflection of a plate is determined and from time hysteresis analysis a Stress-Strain graph will be obtained. Here the original strain length in this case refers to the specimen length 57mm as shown in figure3.

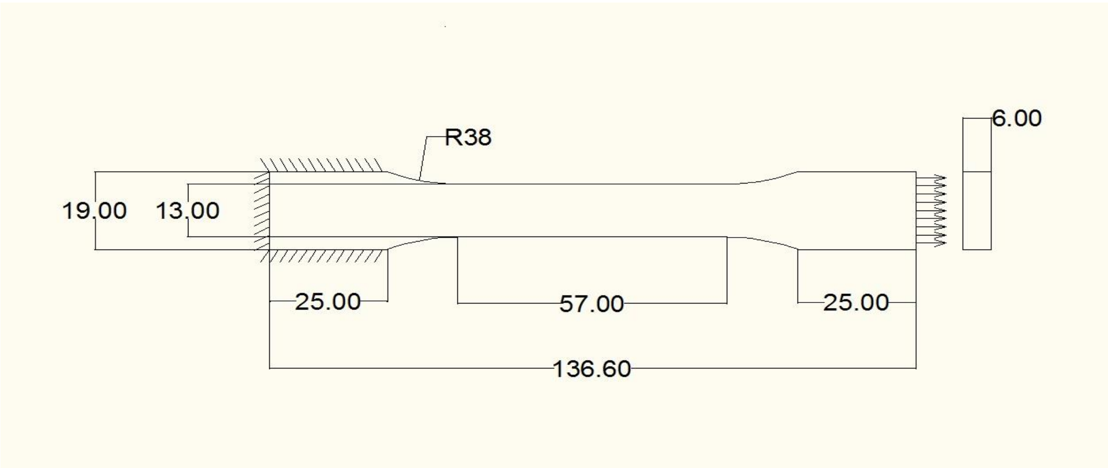

Figure 3: Dog-bone geometry

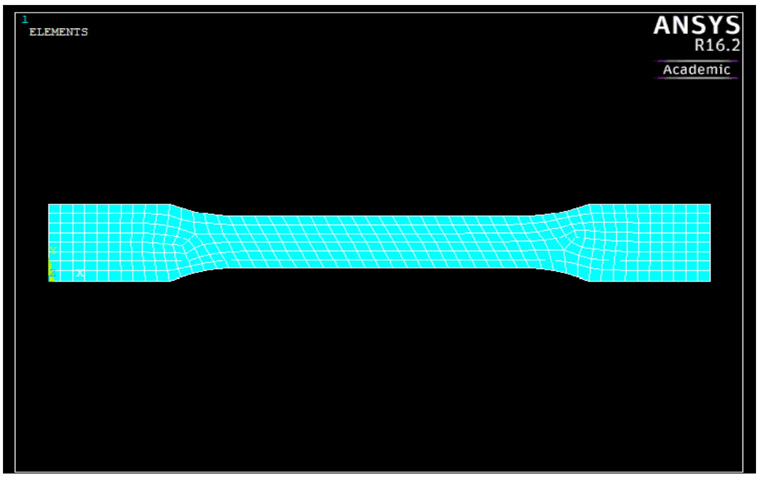

Figure 4: Dog-bone geometry with mesh

RESULTS OBTAINED:

Case 1: The Comparison of Two Plates with a central single circular hole and a central circular hole with two adjacent holes (Triple hole).

Table 1:. Central hole diameter 100mm and maximum strain 0.5.

Models		Single circular hole		Circular hole with two adjacent holes	
		Maximum strain	Maximum stress	Maximum strain	Maximum stress
Mooney Rivlin (Parameters)	2	0.239335	16.18	0.240048	14.1841
	3	0.247005	7.52514	0.247321	6.84716
	5	0.239012	16.4077	0.239741	14.436
Neo-Hookean		0.241522	16.2174	0.242015	14.1471
Ogden (Order)	1	0.240647	15.8986	0.241203	14.0155
	2	0.240136	16.2102	0.240771	14.1537
	3	0.248241	11.7514	0.240751	14.1622

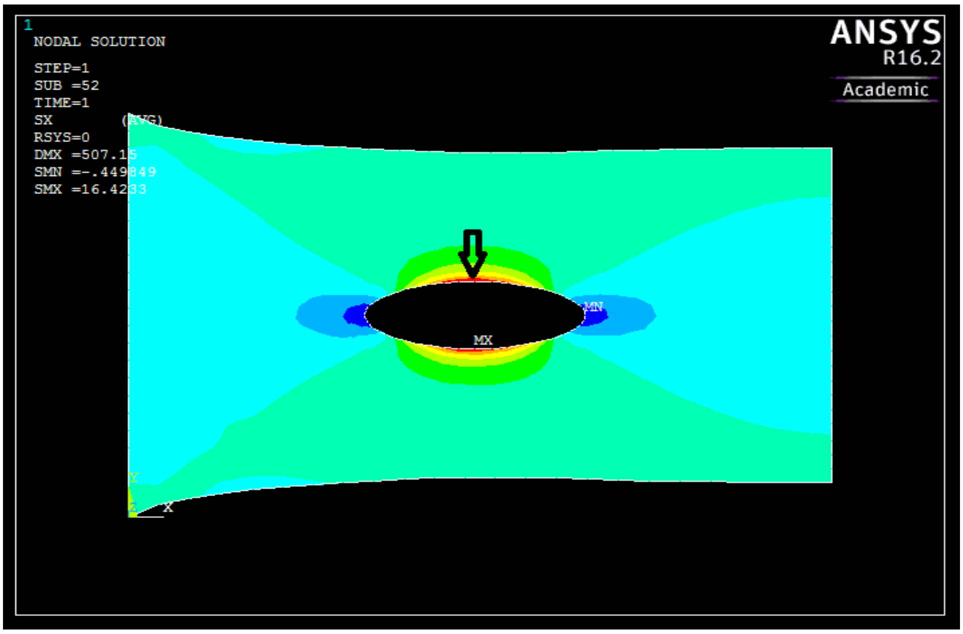

Figure 5: Maximum stress deformation of Mooney-Rivlin 5parameter with 100mm diameter.

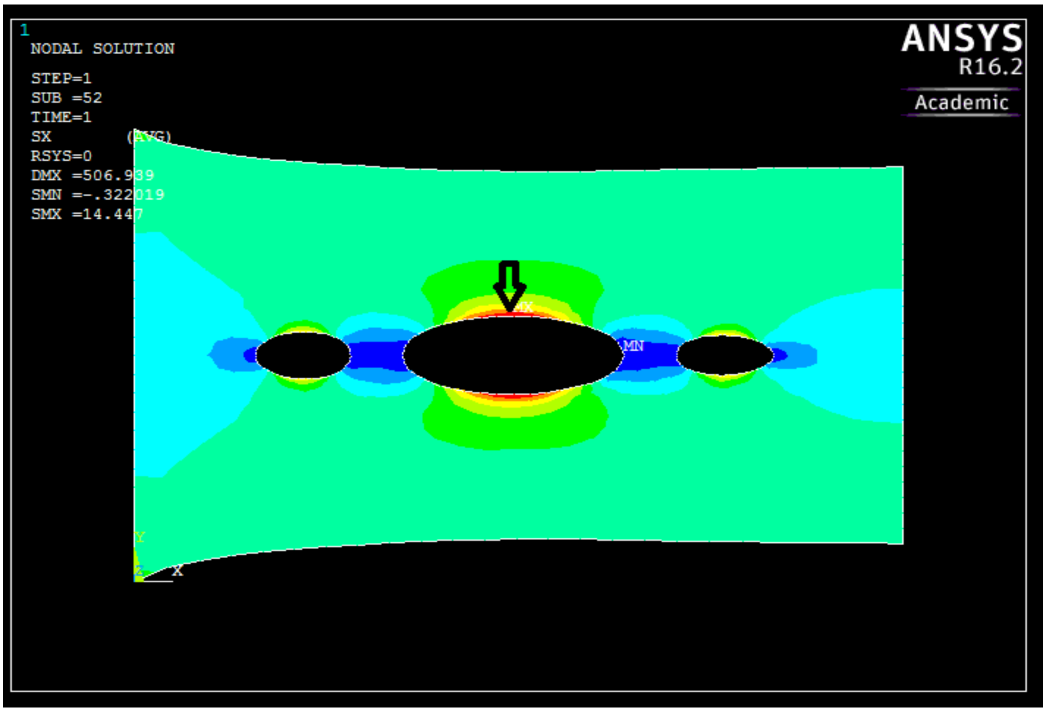

Figure 6: Maximum stress deformation of Mooney-Rivlin 5parameter with 100mm central hole diameter.

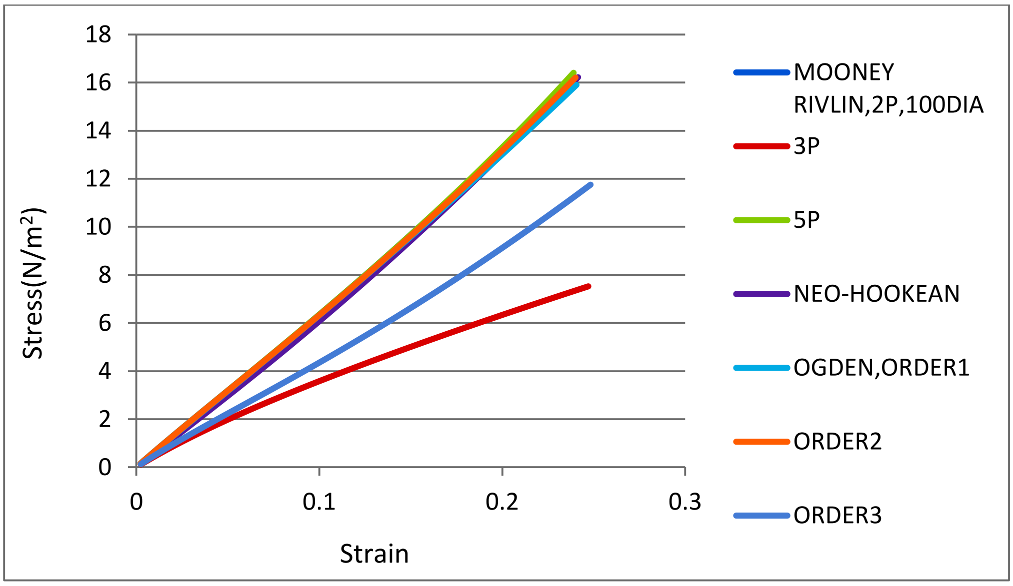

Figure 7: Central single circular hole stress strain values

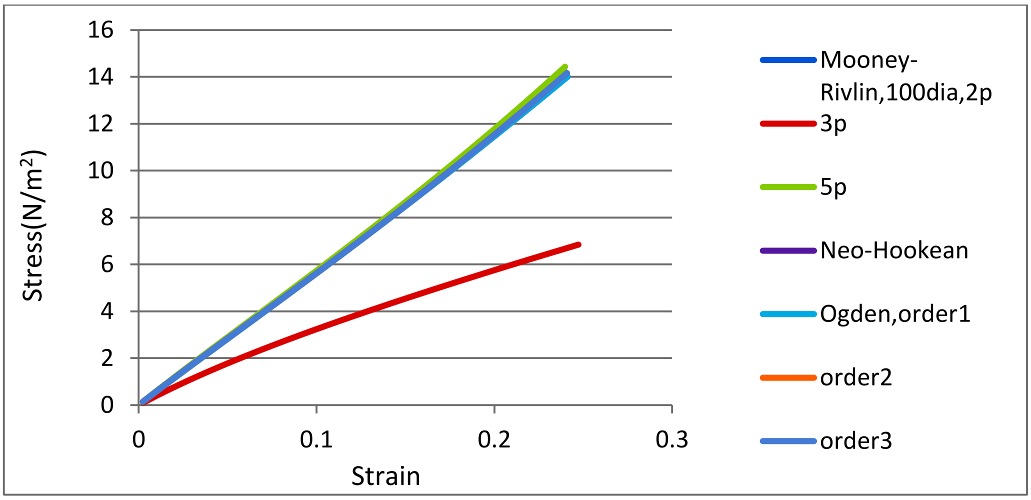

Figure 8: Central circular hole with two adjacent holes stress strain curves

By the Comparison of Two Rectangular plates at 100mm diameter at the strain value of 0.239012(single hole) and 0.239741 (single central hole with two adjacent holes) the Mooney Rivlin 5 parameter will reached the maximum stress values of 16.4077N/m^2 and 14.436N/m^2 at the co-ordinate point (500,600) as shown in figures 5 and 6 with arrow on the top of the hole.

Table 2. Central hole diameter 200mm and maximum strain 0.5.

Models		Single circular hole		Circular hole with two adjacent holes	
		Maximum strain	Maximum stress	Maximum strain	Maximum stress
Mooney Rivlin (Parameters)	2	0.244105	13.5013	0.244147	13.3143
	3	0.248859	6.66774	0.248785	6.60774
	5	0.244028	13.5647	0.244069	13.373
Neo-Hookean		0.244709	13.5515	0.244788	13.3521
Ogden (Order)	1	0.244613	13.3245	0.244669	13.1533
	2	0.244409	13.4688	0.24446	13.2829
	3	0.244644	13.267	0.244452	13.2886

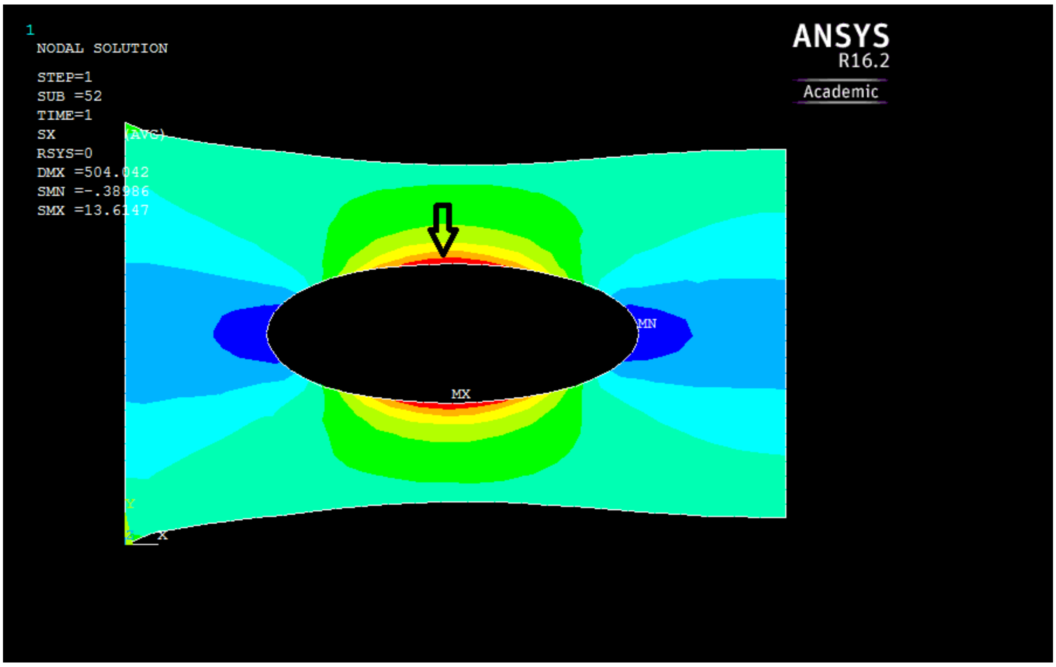

Figure 9: Maximum stress deformation of Mooney-Rivlin 5parameter with 200mm central hole diameter.

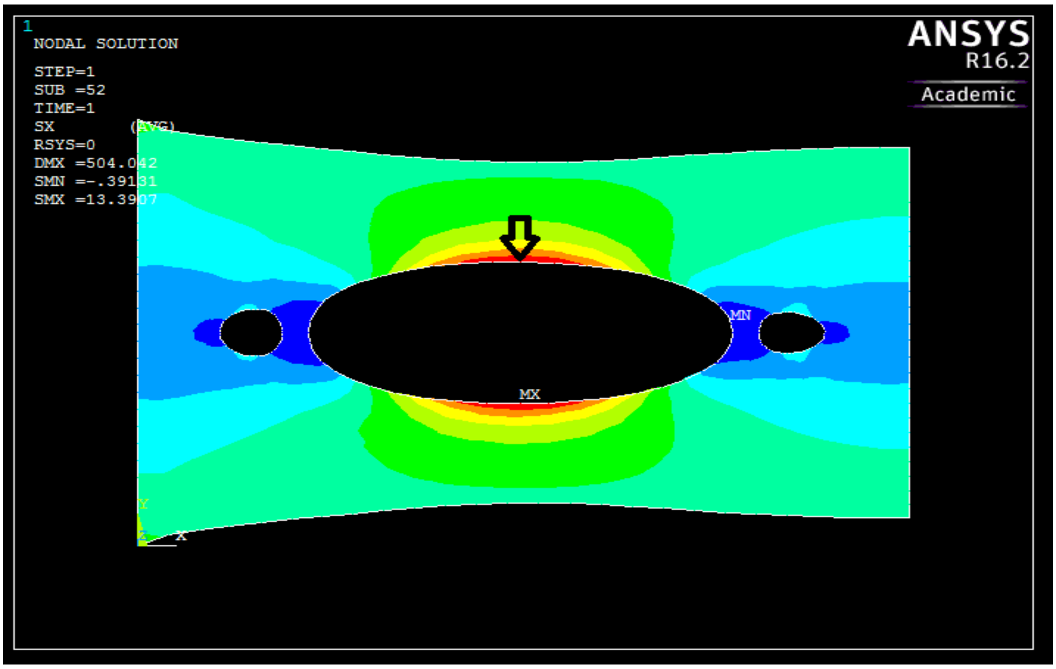

Figure 10: Maximum stress deformation of Mooney-Rivlin 5 parameter with 200mm central hole diameter.

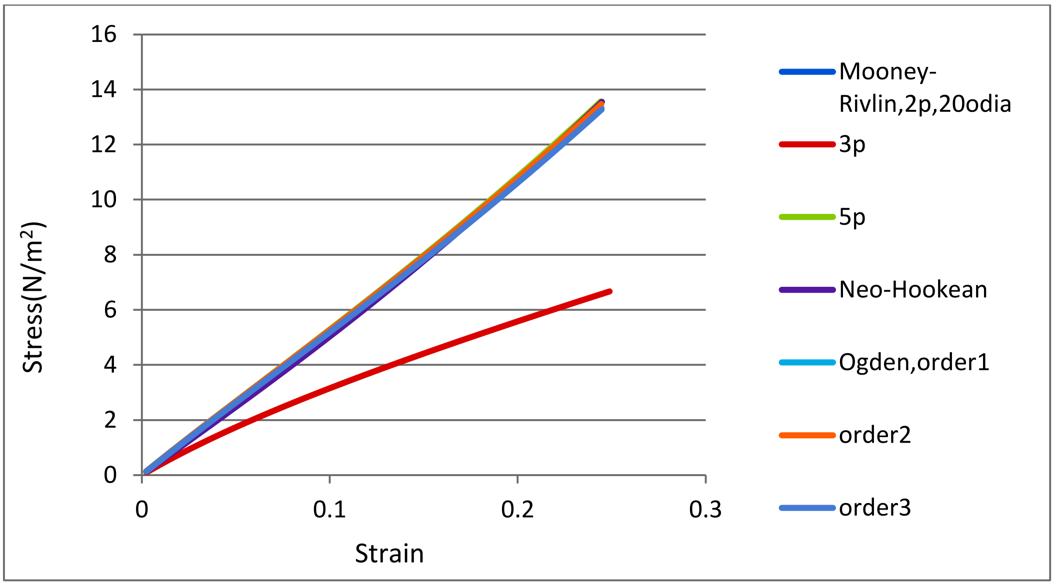

Figure 11: Central single circular hole stress strain values

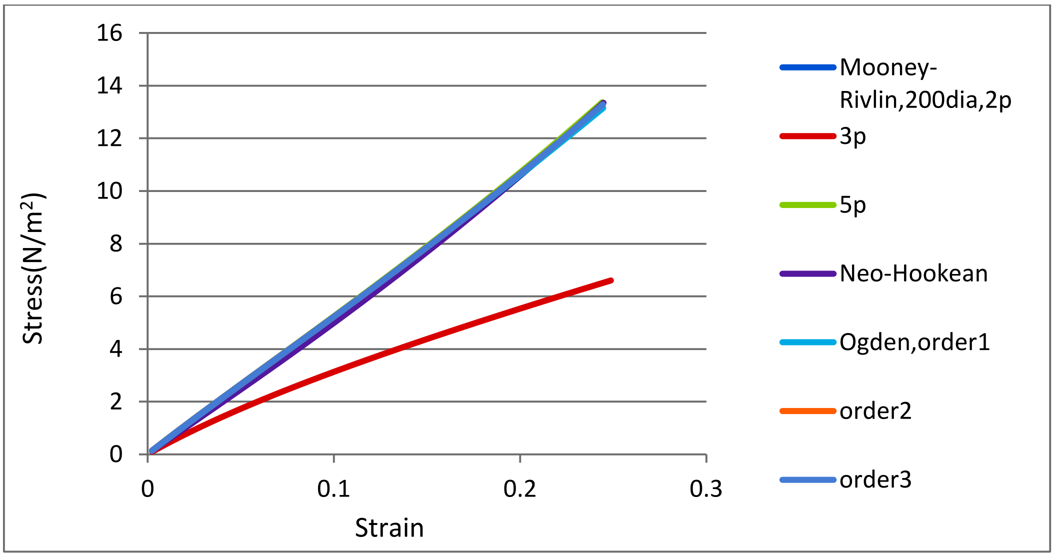

Figure 12: Central circular hole with two adjacent holes stress strain curves.

At 200mm diameter, at the strain value of 0.244028 (single hole) and 0.244069 (single central hole with two adjacent holes) the Mooney Rivlin, 5 parameter will reached the maximum stress values of 13.5647N/m^2 and 13.373N/m^2 at the co-ordinate point (500,700) as shown in figures 9 and 10 with arrow on the top of the hole.

Table 3: Central hole diameter 300mm and maximum strain 0.5.

Models		Single circular hole		Circular hole with two adjacent holes	
		Maximum strain	Maximum stress	Maximum strain	Maximum stress
Mooney Rivlin (Parameters)	2	0.246087	11.4247	0.245939	11.4868
	3	0.248854	5.96336	0.248518	5.99837
	5	0.246046	11.4494	0.245909	11.5112
Neo-Hookean		0.246351	11.421	0.246185	11.4971
Ogden (Order)	1	0.246325	11.3519	0.246123	11.4168
	2	0.246252	11.3937	0.246074	11.4615
	3	0.246248	11.3954	0.246072	11.4631

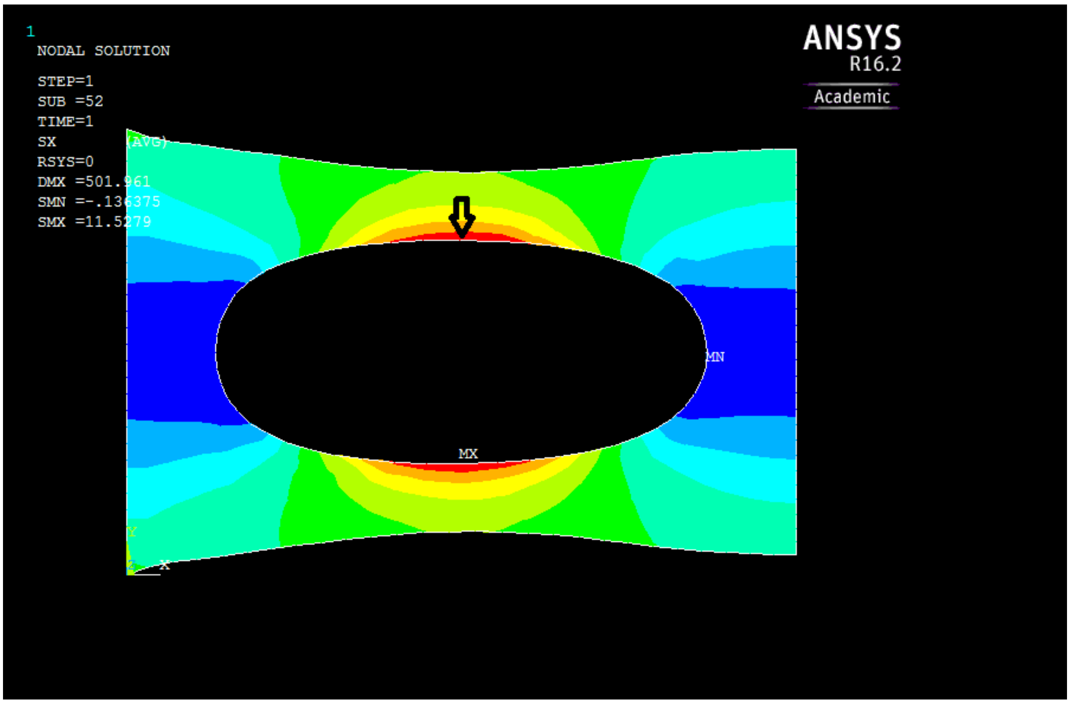

Figure 13: Maximum stress deformation of Mooney-Rivlin 5parameter with 300mm central hole diameter.

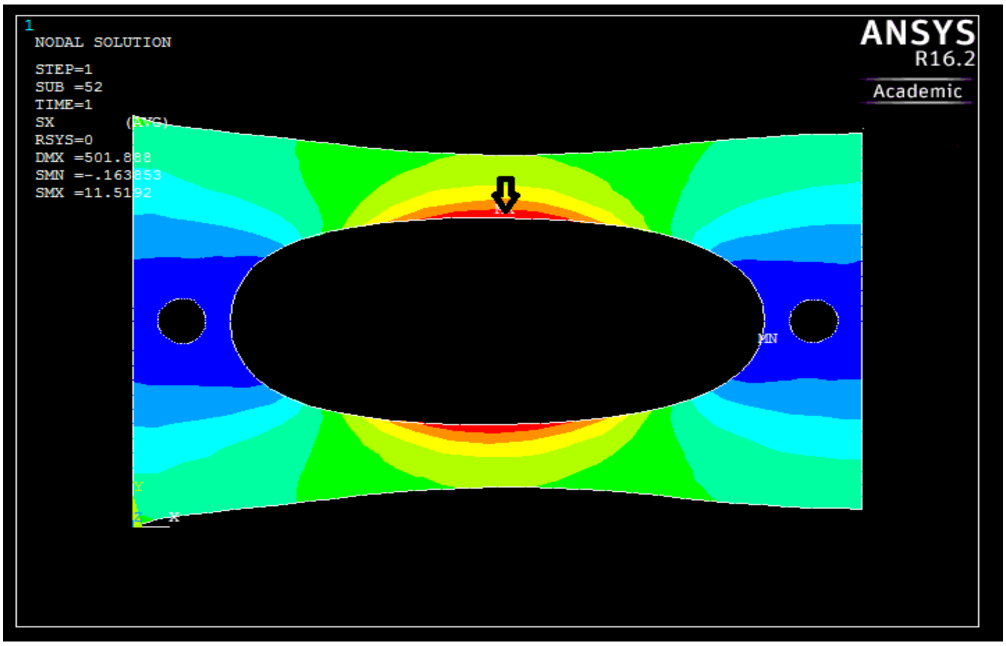

Figure 14: Maximum stress deformation of Mooney-Rivlin 5parameter with 300mm central hole diameter.

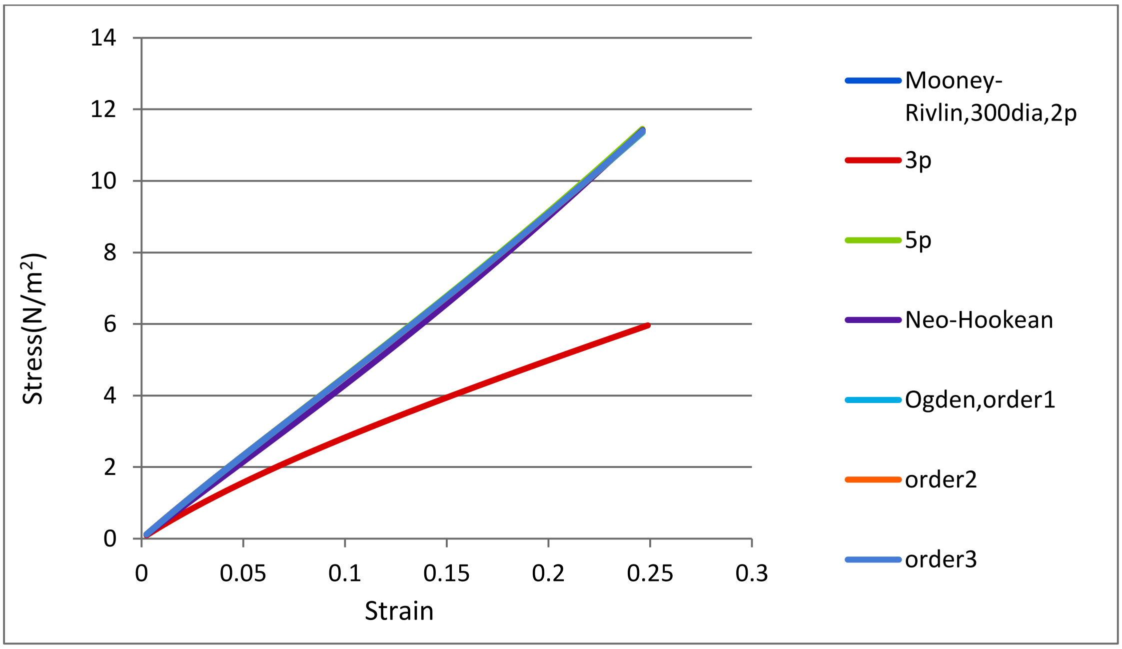

Figure 15: Central single circular hole stress strain values

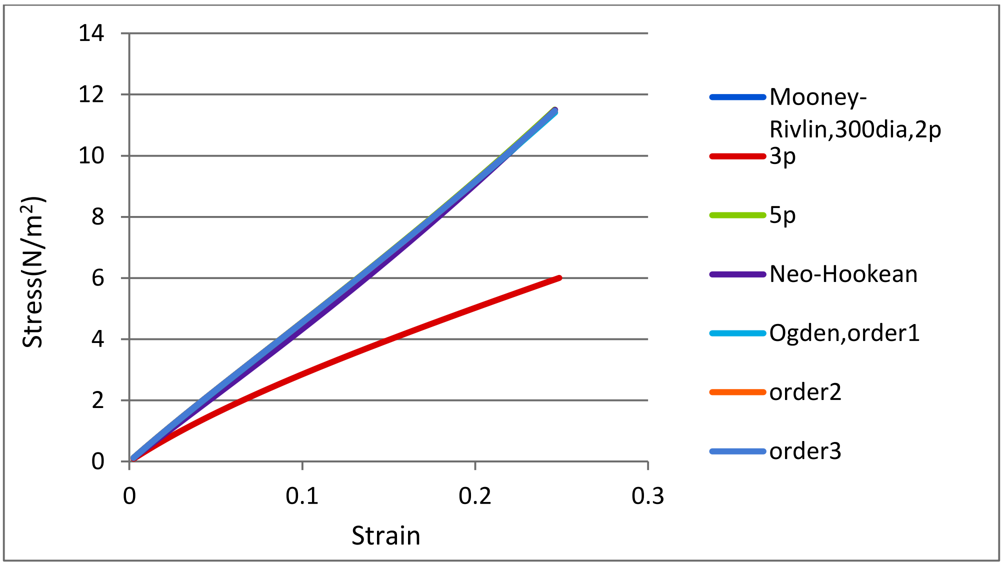

Figure16: Central circular hole with two adjacent holes stress strain curves.

At 300mm diameter, at the strain value of 0.246046 (single hole) and 0.245909 (single central hole with two adjacent holes) the Mooney Rivlin, 5 parameter will reached the maximum stress values of 11.4494N/m^2 and 11.5112N/m^2 at the co-ordinate point (500,800) as shown in figures 13 and 14 with arrow on the top of the hole.

Case 2: Dog-bone geometry

Table 4: Stress comparison of the models

Strain (%)	Maximum stress N/m^2						
	Mooney-Rivlin (Parameters)			Neo-Hookean	Ogden (Orders)		
	2	3	5		1	2	3
10	0.731882	0.72886	0.727932	0.727932	0.718268	0.726833	0.726813
20	1.41481	1.41241	1.4117	0.749364	0.749364	1.41264	1.41257
30	2.06372	2.06413	2.06587	1.10694	2.06327	2.06327	2.0677
40	2.68871	2.69312	2.6986	1.45674	2.70443	2.69947	2.69954
50	3.29688	3.30574	3.31483	1.80096	3.3305	3.31318	3.31344
60	3.89343	3.90663	3.91789	2.14153	3.94425	3.91311	3.91359
70	4.48237	4.49931	4.51044	2.48009	4.54771	4.50276	4.50343
80	5.07711	5.09684	5.10505	2.82402	5.1528	5.09537	5.09612
90	5.64959	5.67067	5.67355	3.15677	5.7297	5.66317	5.66388

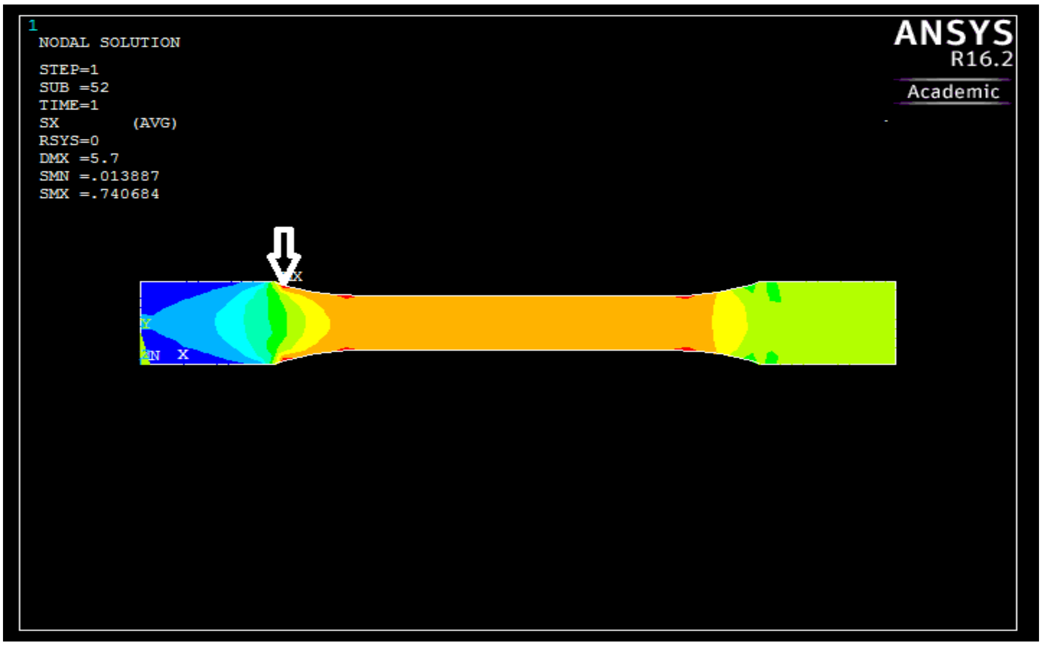

Figure17: Maximum stress deformation of Mooney-Rivlin 2 parameter with 10% Strain

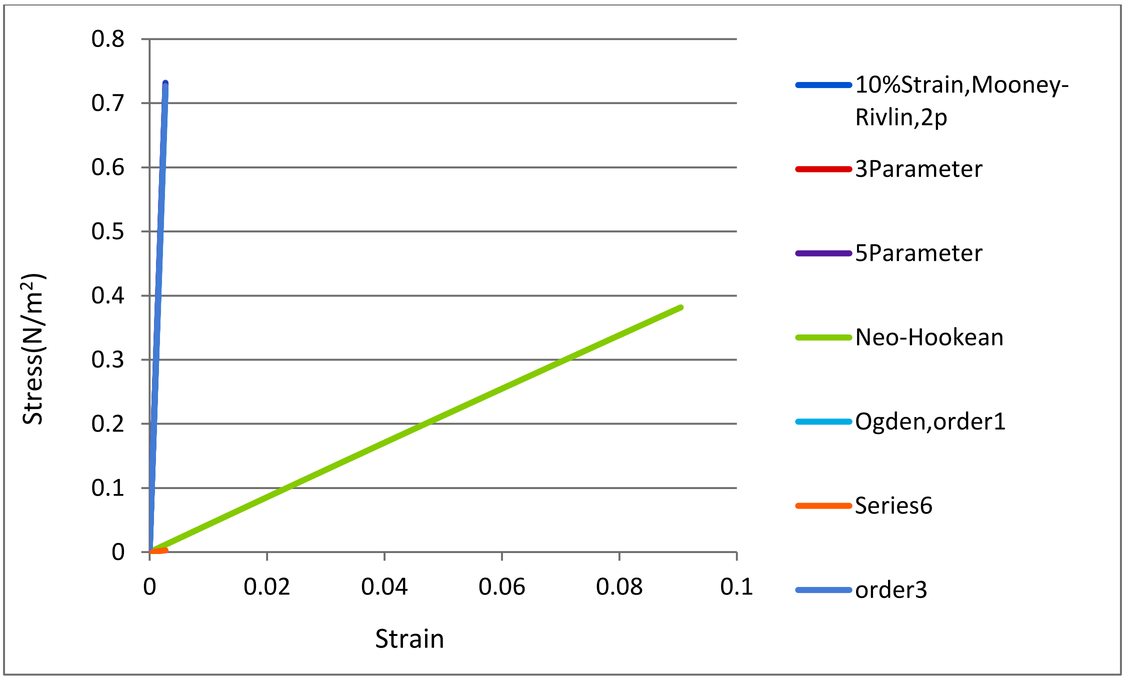

Figure18: At 10% of strain Mooney-Rivlin, 2parameter will take the highest stress value 0.731882 N/m^2

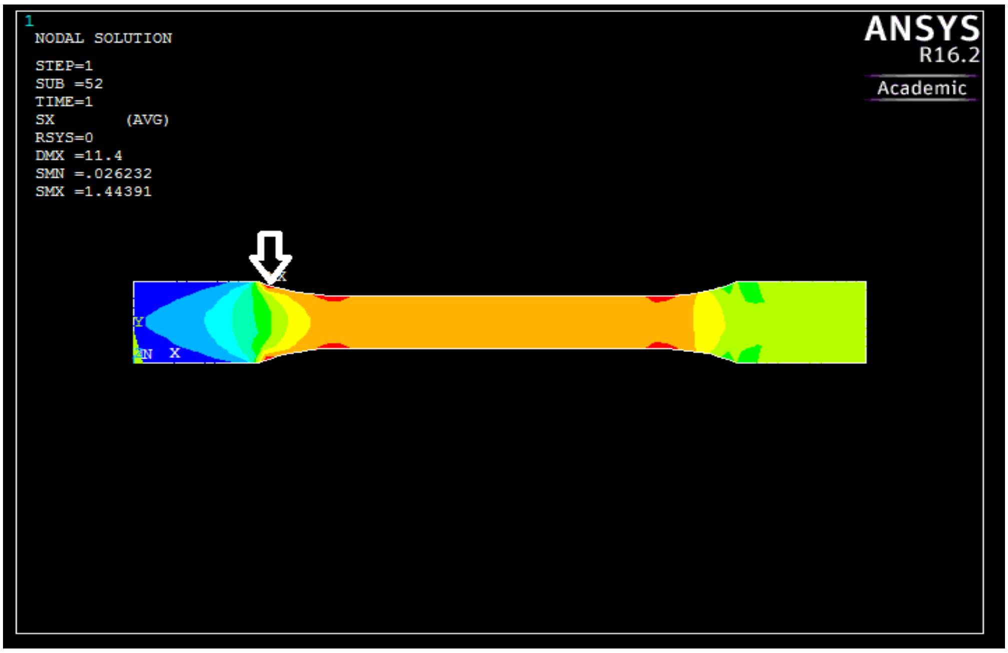

Figure 19: Maximum stress deformation of Mooney-Rivlin 2 parameter with 20% Strain

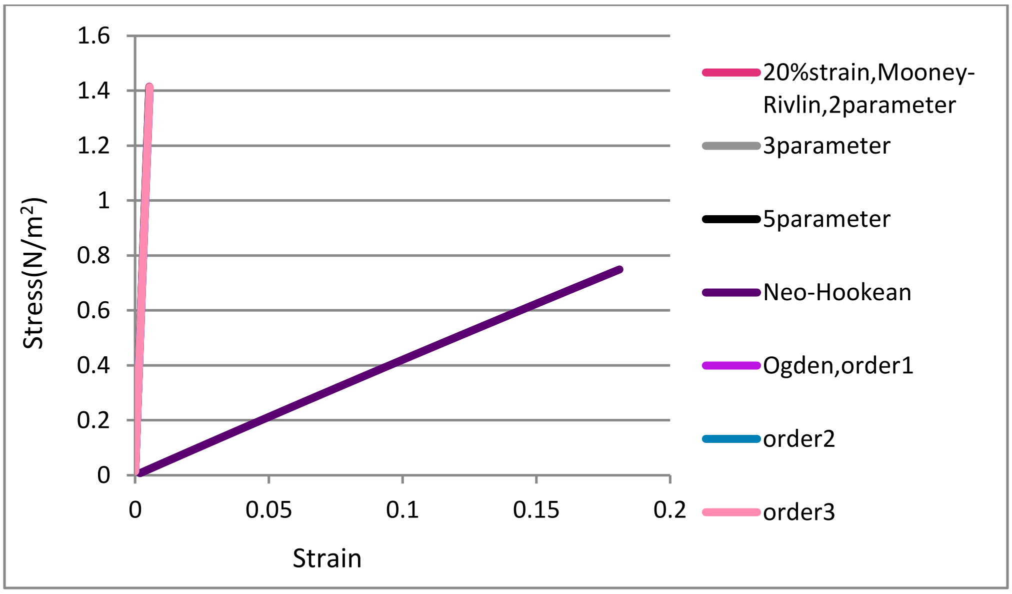

Figure 20: At 20% of strain Mooney-Rivlin, 2parameter will take the highest stress value 1.41481 N/m^2

From figures-18 and 20, it can be observed that the Mooney-Rivlin 2parameter model had shown greater stresses at the co-ordinate points (26.600, 18.366) as shown in the figures 17 and 19 with the arrow.

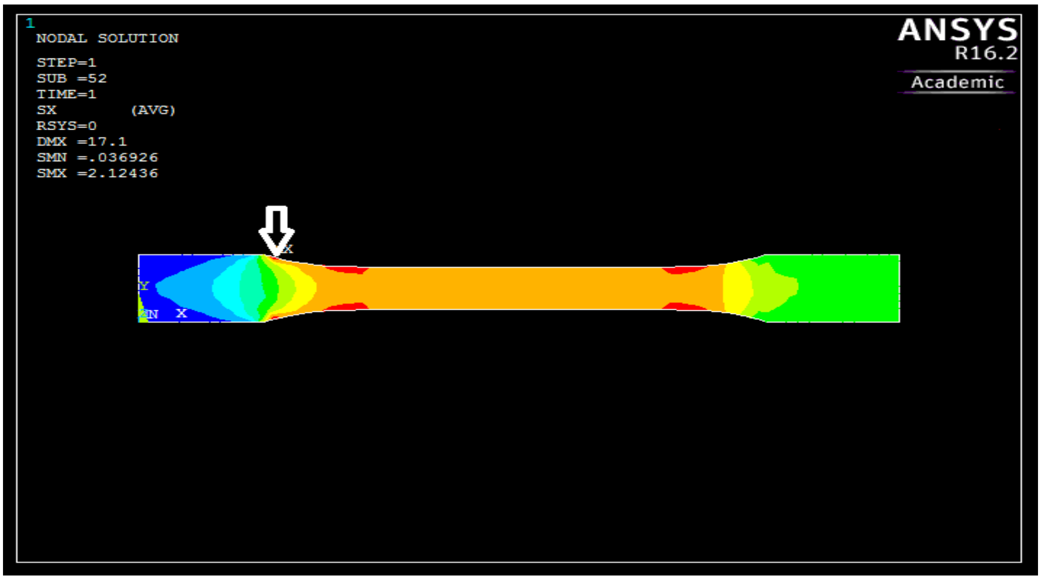

Figure 21: Maximum stress deformation of Ogden, order3 with 30% Strain

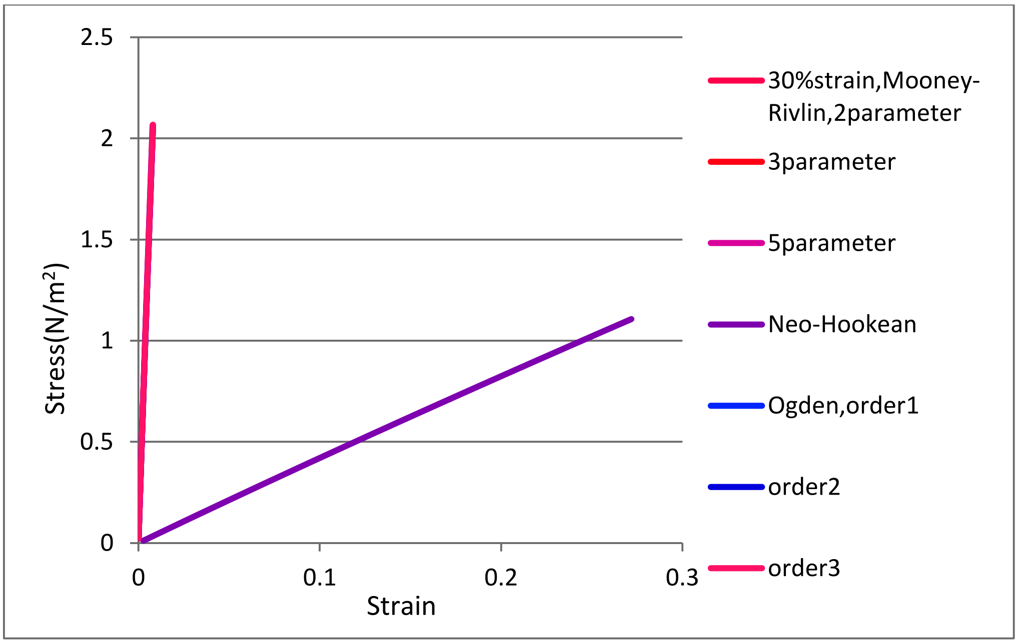

Figure 22: At 30% of displacement Ogden, order3 will take the highest stress value 2.0677 N/m^2 at the co-ordinate points (26.600, 18.366) as shown in the figure 21 with the arrow.

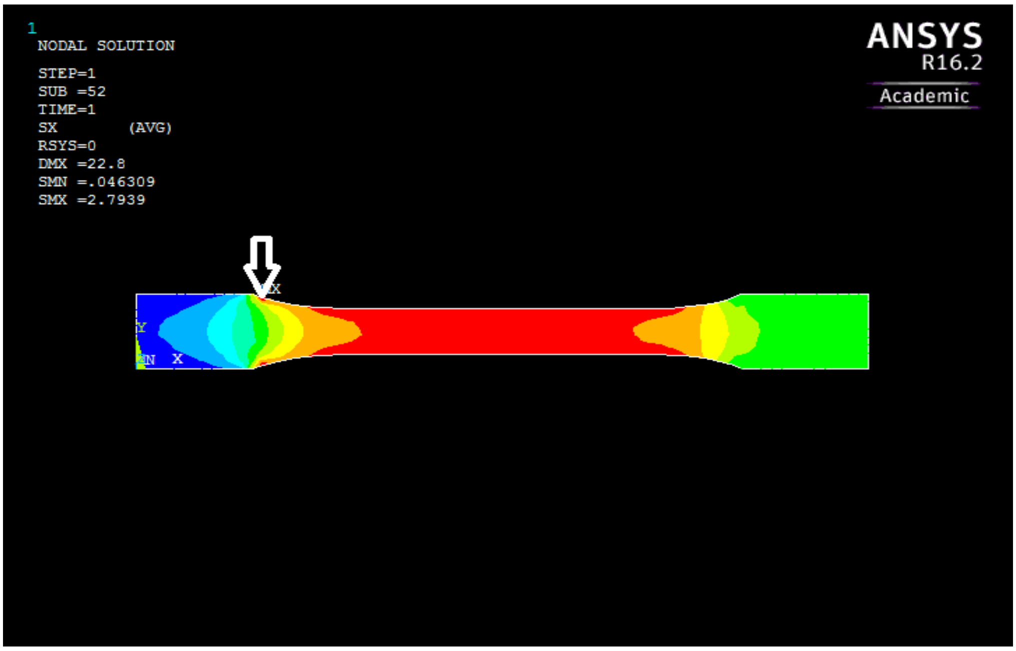

Figure 23: Maximum stress deformation of Ogden, order1 with 40% Strain

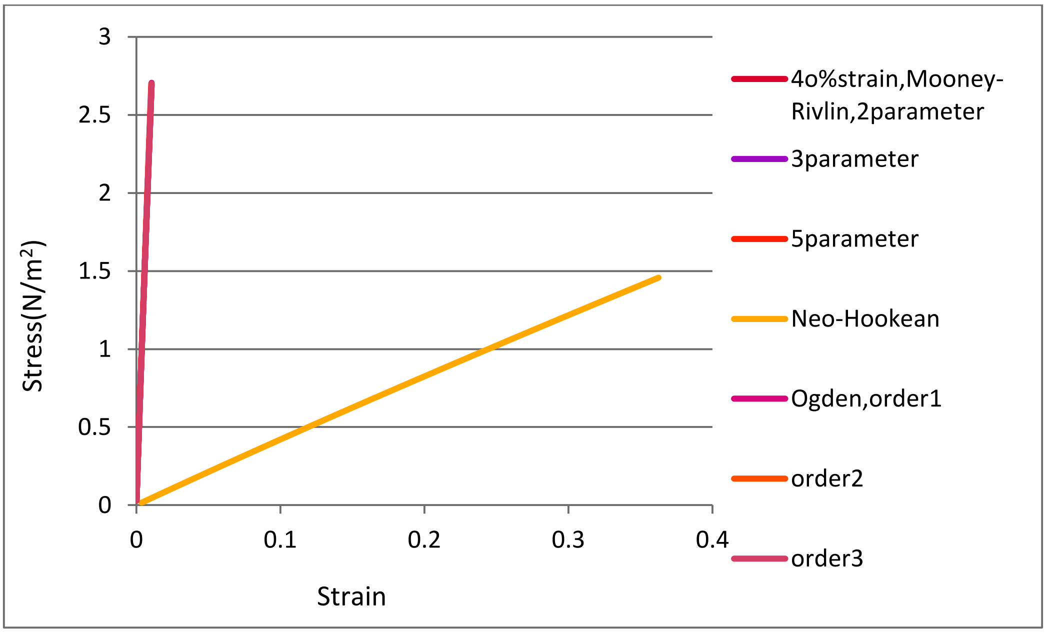

Figure 24: At 40% of displacement Ogden, order 1 will take the highest stress value 2.70443 N/m^2.

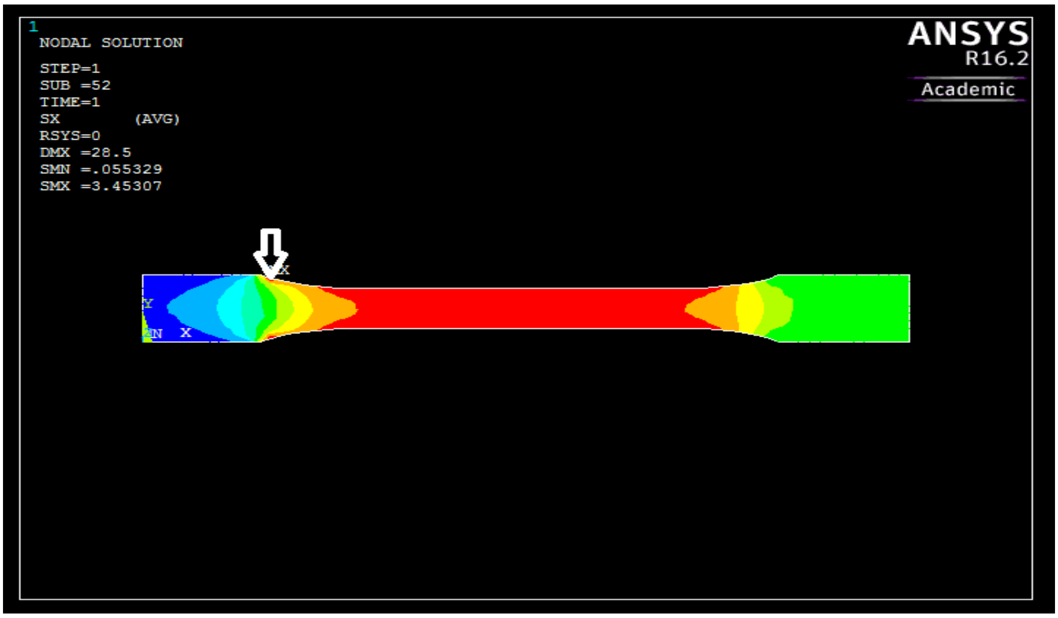

Figure 25: Maximum stress deformation of Ogden, order1 with 50% Strain

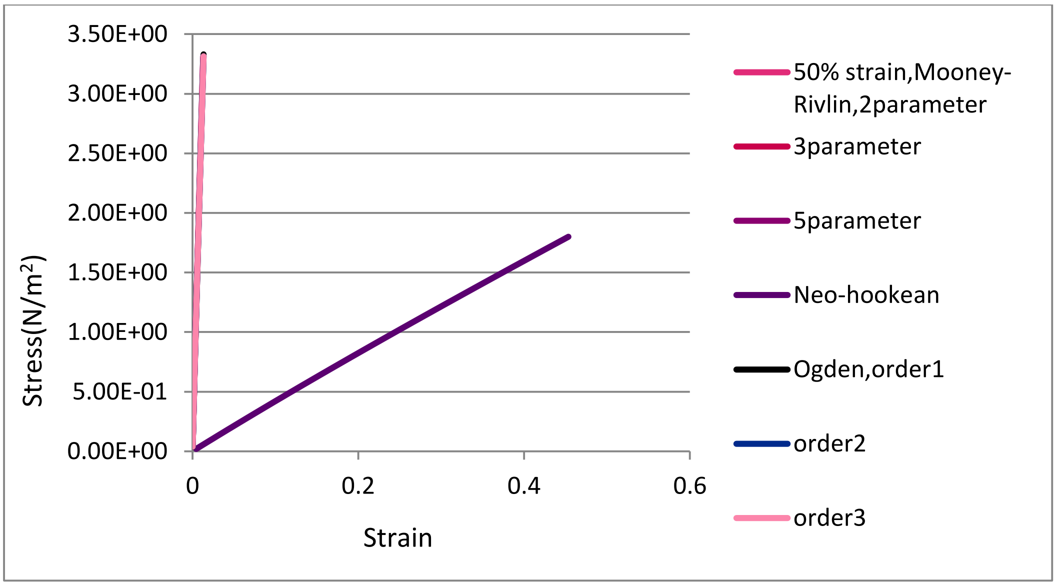

Figure 26: At 50% of displacement Ogden, order1 will take the highest stress value 3.3305 N/m^2

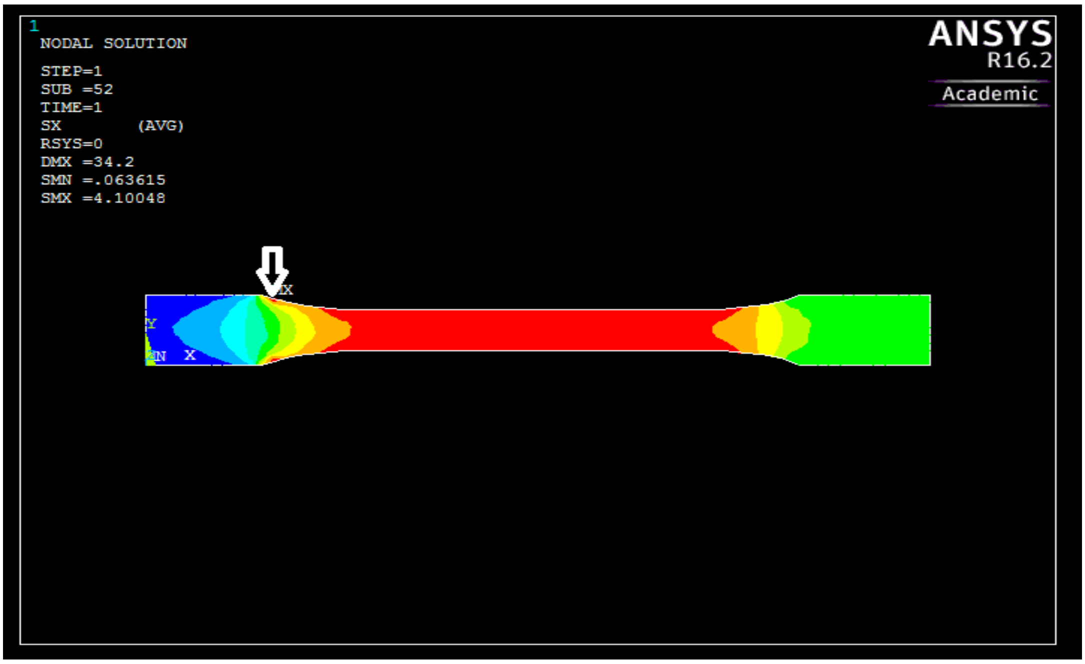

Figure 27: Maximum stress deformation of Ogden, order1 with 60% Strain

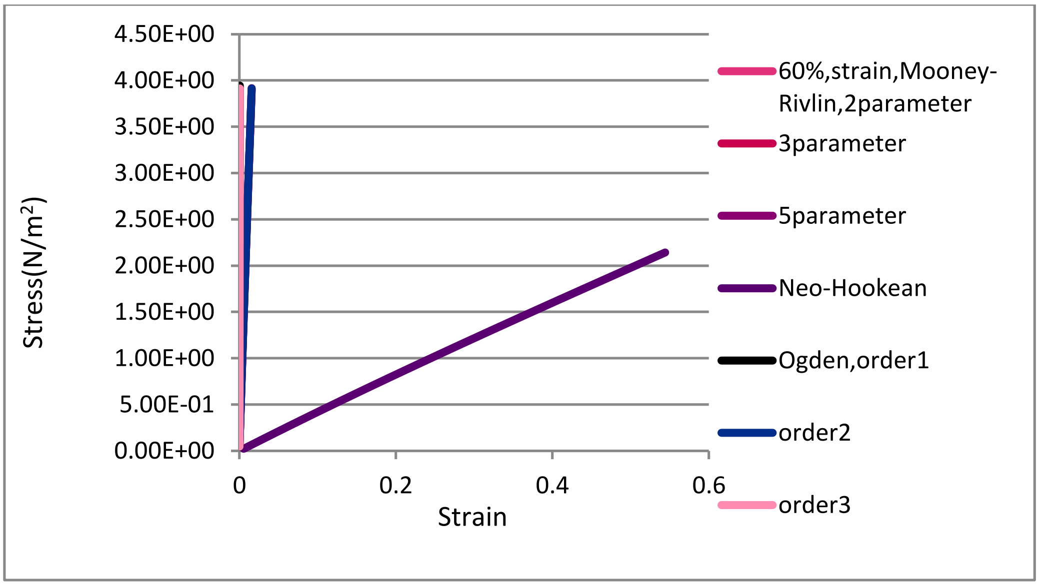

Figure 28: At 60% of strain Ogden, order1 will take the highest stress value 3.94425 N/m^2

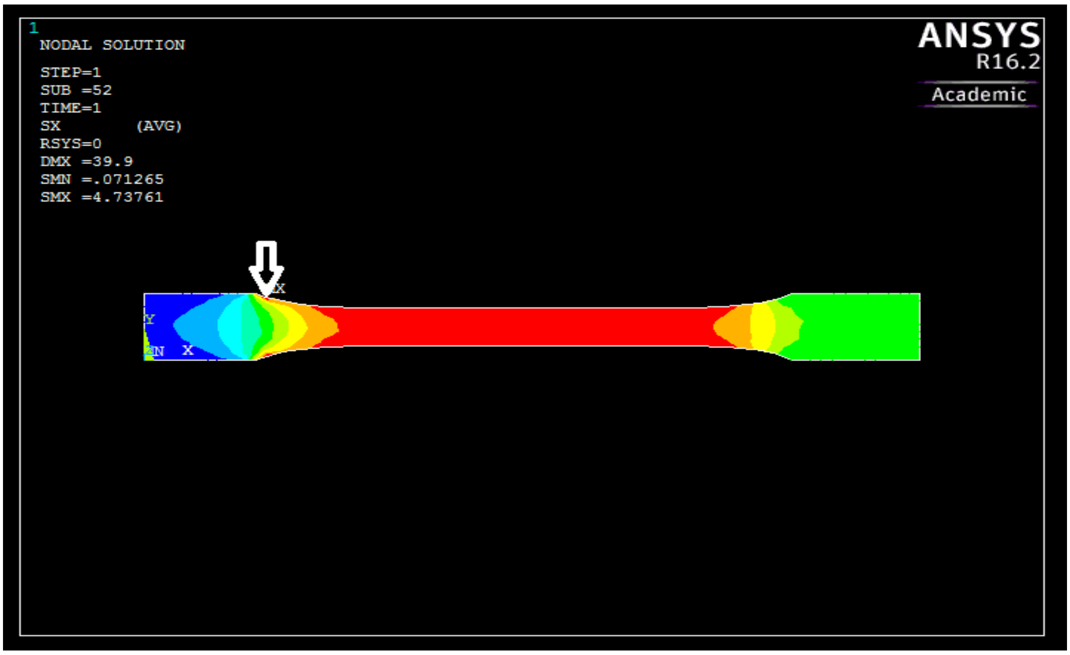

Figure 29: Maximum stress deformation of Ogden, order1 with 70% Strain

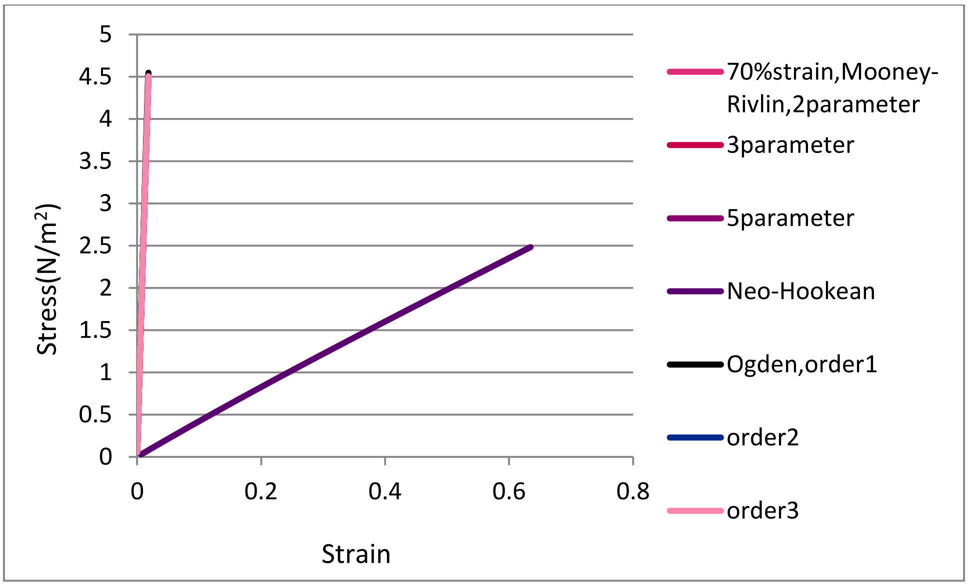

Figure 30: At 70% of strain Ogden, order1 will take the highest stress value 4.54771 N/m^2

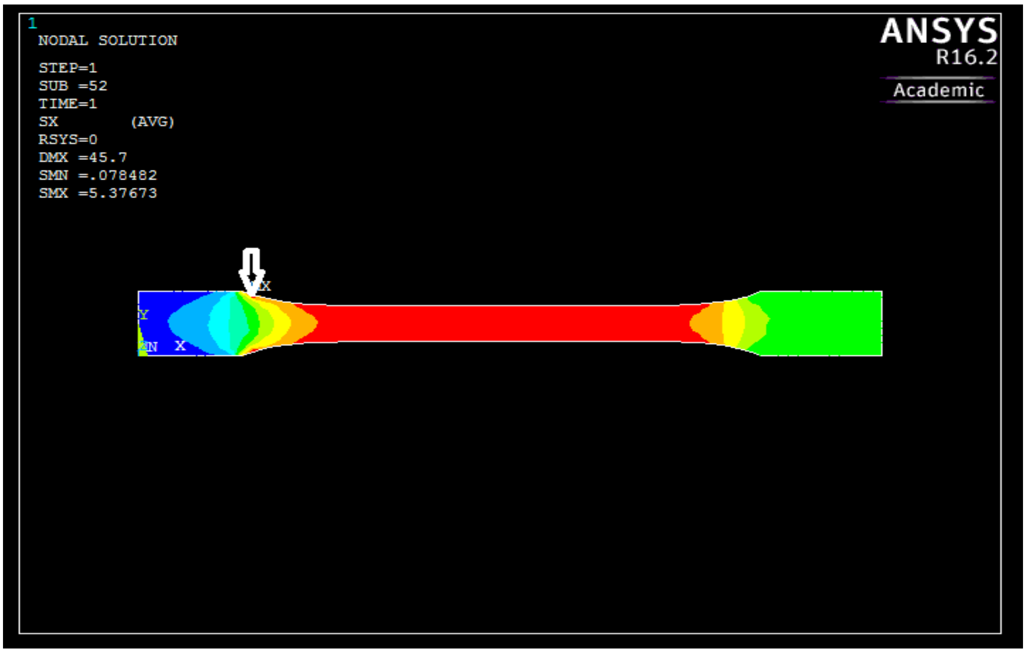

Figure 31: Maximum stress deformation of Ogden, order1 with 80% Strain

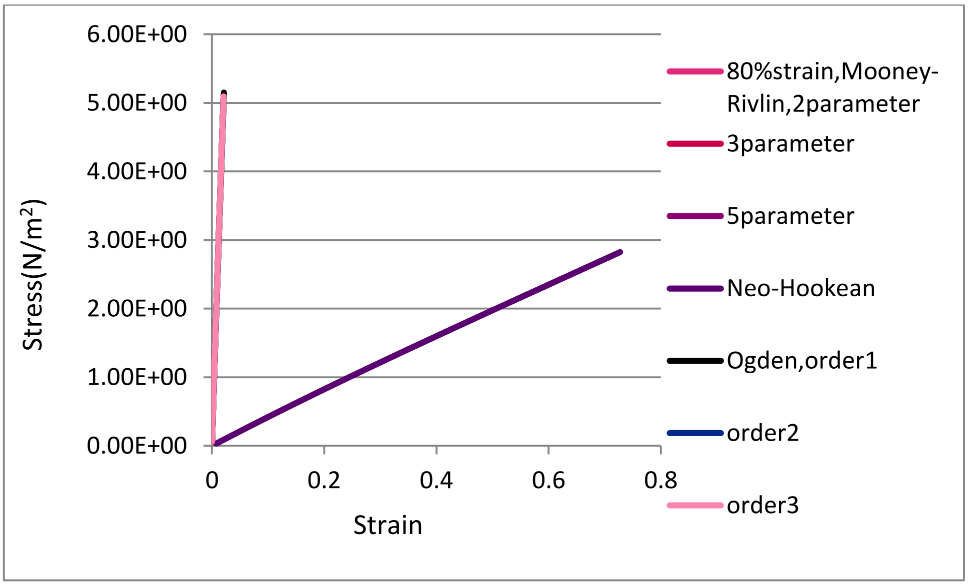

Figure 32: At 80% of strain Ogden, order1 will take the highest stress value 5.1528 N/m^2

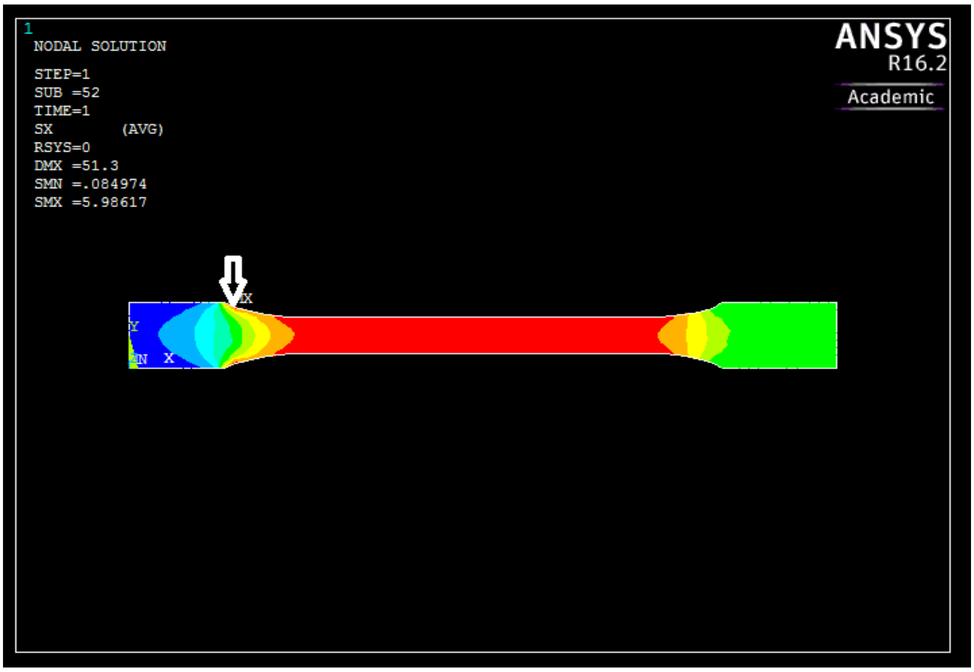

Figure 33: Maximum stress deformation of Ogden, order1 with 90% Strain

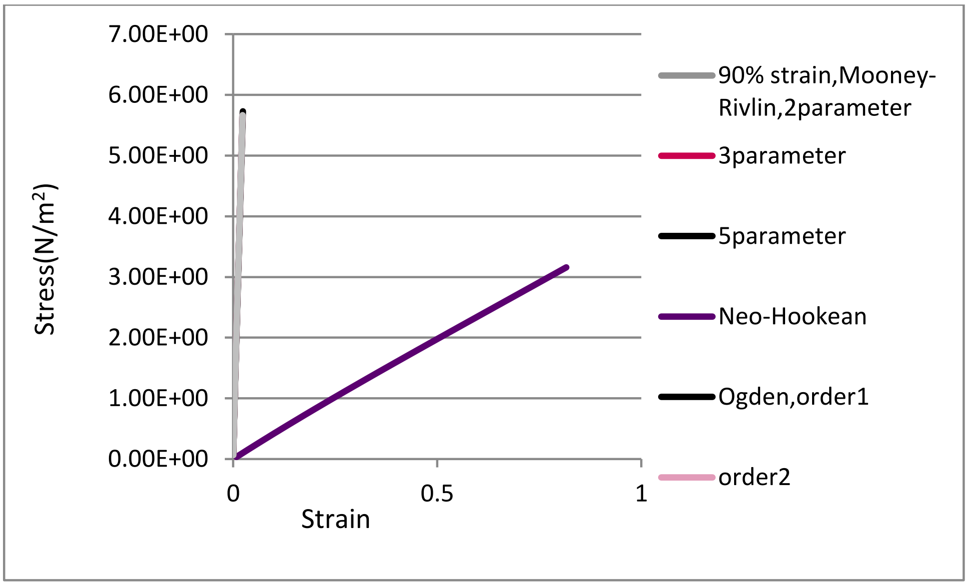

Figure 34: At 90% of strain Ogden, order1 will take the highest stress value 5.7297 N/m^2

From figures 23 to 34, it can be observed that the Ogden, order1 model had shown greater stresses at the co-ordinate points (26.600, 18.366) as shown in the stress deformation figures with the arrow.

CONCLUSIONS

According to this analysis, the order of constants or model had been increased with the increase of hole diameter and displacement values. By the comparison of two plates with the single central hole and the central hole with two adjacent holes (triple hole), at 100 and 200mm diameter Mooney-Rivlin 5parameter single hole geometry had shown greater stresses and for 300mm diameter Mooney-Rivlin 5parameter triple hole geometry had shown greater stresses than the single hole geometry. With increase of hole diameter the stress value had been increased around the hole.

In Dog-bone geometry, with increase of strain value the non-linear model parameters had been increased according to their relative stiffness. For 10-20% strain the Mooney-Rivlin 2 parameter, 30% strain Ogden order3 and 40-90% strain Ogden order1 had shown greater stresses than the other models. The higher the model the more accurate stress-strain curves will be obtained.

REFERENCES

[1] G.Marckmann, E.Veron, "comparison of hyper elastic models for rubber-like materials", Rubber chemistry and technology, 2014, 79, 835-858.

[2] Kurt Miller, "Testing Elastomers for Hyper elastic Material Models in Finite Element Analysis", 2002, Axel Products, Inc.

[3] Prashant Nimbalkar, "Approach of Mooney- Rivlin material Model in Air Intake System", International Journal of Science, Engineering and Technology Research, 2015, 4, 4294-4296.

[4] Tie Hu, Jaydev P. Desai, "Modelling Large Deformation in Soft-tissues", Experimental results and Analysis Proceedings of eurohaptics, 2004.

[5] Vishal Nayyar, K. Ravi-Chandar and Rui Huang, "Stretch-induced stress patterns and wrinkles in hyper elastic thin sheets", International journal of solids and structures, 2011, volume 48.