International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 4, No. 3, August 2015

Research Paper

INVESTIGATION OF STRESSES IN BI-MATERIAL STRIP WITH DISCONTINUITIES

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Stresses in a bi-material strip with discontinuities subjected to temperature gradient that varies linearly in longitudinal direction are studied using FE analysis. The discontinuities considered are, transverse through hole and longitudinal hole. For longitudinal hole total area is equally divided by upper strip with low coefficient of thermal expansion and lower strip with high coefficient of thermal expansion. The diameter and depth of hole is varied for analysis and its effects are studied using FEM.

Keywords: Bi-material strip, Axial temperature gradient, FEM, Thermal loading

INTRODUCTION

Bi-material strip consist of two metals with different coefficients of thermal expansion bonded together. As the temperature varies from the temperature at which the metals were bonded, the metals expand by different amounts and the composite experiences a shearing force.

A bi-material strip is used to convert a temperature change into mechanical displacement. The strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper, or in some cases brass instead of copper. The strips are joined together throughout their length by riveting, brazing or welding. The different expansions force the flat strip to bend one way if heated, and in the opposite direction if cooled below its initial temperature. The metal with the higher coefficient of thermal expansion is on the outer side of the curve when the strip is heated and on the inner side when cooled.

The sideways displacement of the strip is much larger than the small lengthways expansion in either of the two metals. This effect is used in a range of mechanical and electrical devices. In some applications the bimetal strip is used in the flat form. In others, it is wrapped into a coil for compactness. The greater length of the coiled version gives improved sensitivity.

In present work, the bi-material strip with discontinuities is considered for analysis. For specific study discontinuities like transverse

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through hole, longitudinal hole by varying diameter and depth of hole is considered. The FE analysis is carried out and the effect of discontinuities on stresses in bi-material strip subjected to constant temperature and axial temperature gradient is studied.

DESIGN PARAMETER AND MATERIAL

The Bi-material strip made of steel and brass with equal length, breadth and thickness subjected to constant temperature and axial temperature gradient is considered. The FE analysis is carried out by using following specifications

Constant Load Temp = 100 °C

Axial temperature gradient = 0 to 100 °C

Length of Bi-material strip L = 200 mm

Width of steel plate b = 50 mm

Thickness of steel plate t = 10 mm

Width of the brass plate b = 50 mm

Thickness of brass plate t = 10 mm

Transverse through hole diameter variation = 20 to 40 mm

Longitudinal hole diameter variation = 5 to 15 mm

Longitudinal hole depth variation = 10 to 50 mm

The design parameters of bi-material strip are shown in Table 1.

Table 1: Design Parameters of Bi-material Strip Combination

Parameter	Steel	Brass
Young's Modulus E (N/mm^2)	2×10^5	1×10^5
Coefficient of Thermal Expansion (/^{0}C)	11×10^{-6}	16.5×10^{-6}
Poisson's Ratio	0.3	0.15

METHODOLOGIES

Finite Element Analysis

For the analysis purpose 3-D models are prepared using ANSYS. FE analysis is carried out with 20-node SOLID95 3D structural solid element, by applying constant temperature and axial temperature gradient. The materials considered are Steel and Brass. The properties of material are provided and mesh model is developed. The analysis is done by varying diameter of transverse hole in steps of 10 mm

Figure 1: First Principle Stress Counter for Bi-material Strip Subjected to Constant Temperature

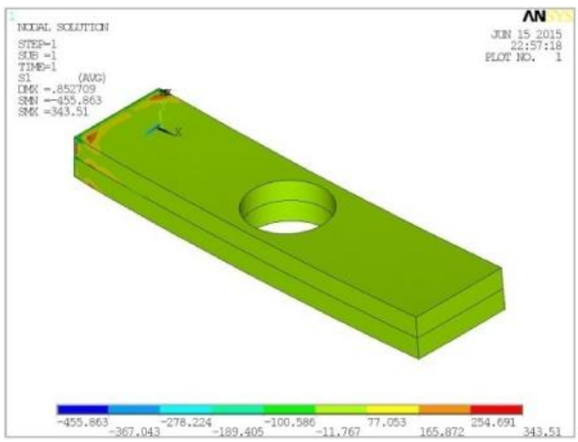


Figure 2: First Principle Stress Counter for Bi-material Strip Subjected to Axial Temperature Gradient

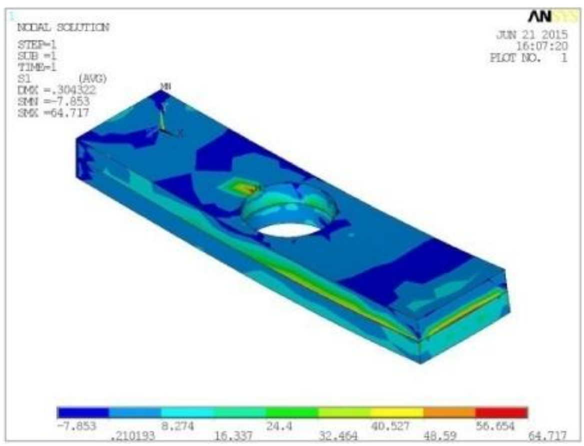


Figure 3: First Principle Stress Counter for Bi-material Strip Subjected to Constant Temperature

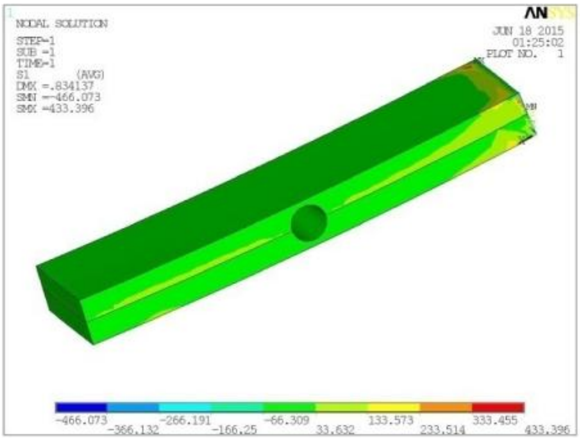
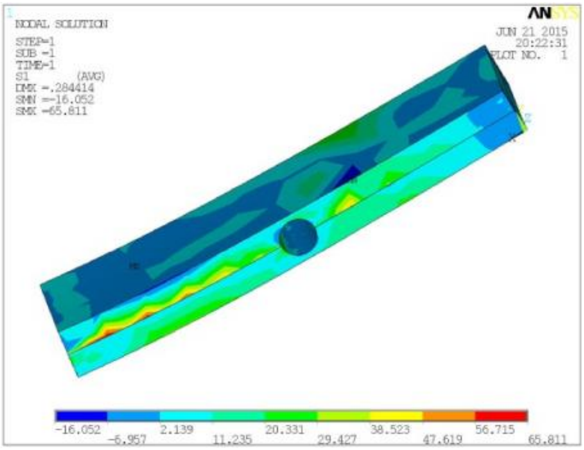


Figure 4: First Principle Stress Counter for Bi-material Strip Subjected to Axial Temperature Gradient



from 20 mm to 40 mm. After solving, the first principle stress contour at nodal region is shown in Figures 1 and 2. Analysis is also carried out for variation in depth and diameter of longitudinal hole considered as discontinuity. The first principle stress contour is shown in Figures 3 and 4.

COMPARISON OF RESULTS

To study the effect of discontinuities on stresses in Bi-material strip the transverse through hole diameter is varied in steps from 20 mm to 40 mm. The results are tabulated in Tables 2 and 3. The depth and diameter of longitudinal hole is varied and the results are tabulated in Tables 4 and 5.

Figure 5: Variation in Stresses for Change in Diameter of Transverse Through Hole

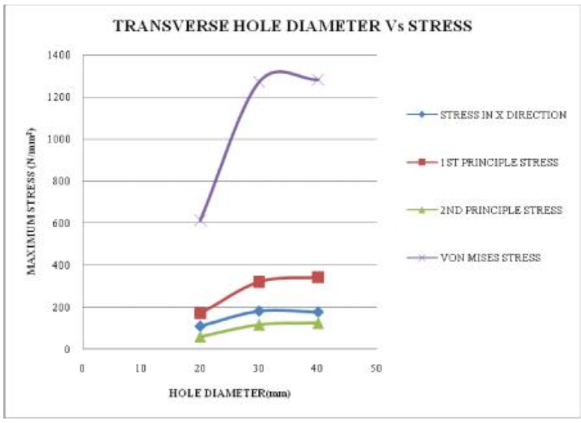


Table 2: Comparison of Stresses and Deflection for the Bi-material Strip Subjected to Constant Temperature by Varying Diameter of Transverse Through Hole

Diameter of through transverse hole (mm)	Normal stress in X direction (N/mm^2)	First Principle stress (N/mm^2)	Second principle stress (N/mm^2)	Von-mises stress (N/mm^2)	Deflection (mm)
20	109.04	170.61	58.775	613.085	0.426
30	179.74	321.69	115.27	1272	0.852
40	175.28	343.51	123.28	1283	0.853

Table 3: Comparison of Stresses and Deflection for the Bi-material Strip Subjected to Axial Temperature Gradient by Varying Diameter of Through Hole

Diameter of through Transverse hole (mm)	Normal Stress in X direction (N/mm^2)	First Principle Stress (N/mm^2)	Second Principle Stress (N/mm^2)	Von-mises Stress (N/mm^2)	Deflection (mm)
20	120.296	120.497	93.394	166.426	0.306
30	54.503	61.424	54.278	94.239	0.3
40	54.225	64.717	52.361	117.827	0.304

Figure 6: Variation in Stresses for Change in Hole Diameter of Bi-material Strip Subjected to Axial Temperature Gradient

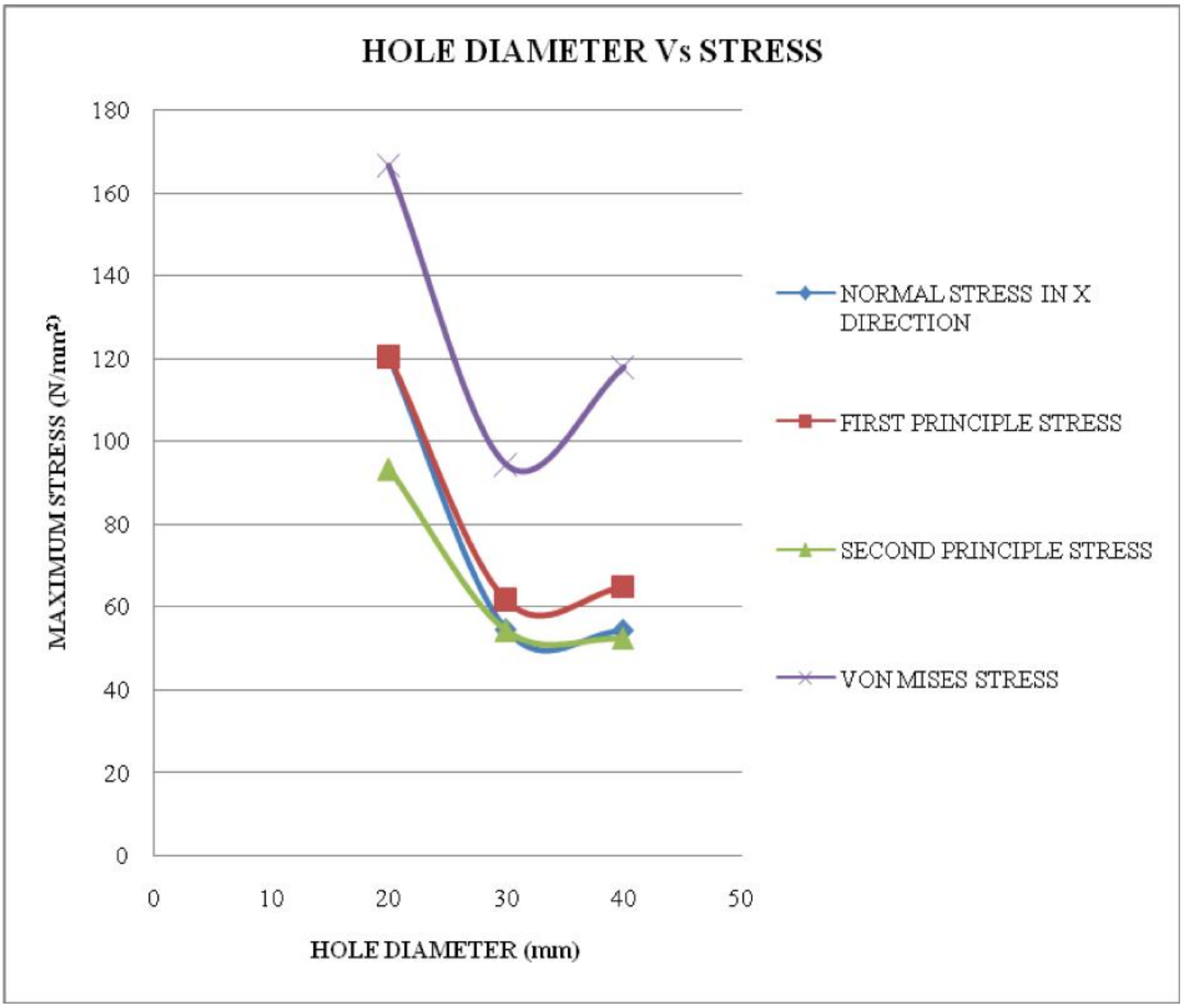


Table 4: Comparison of Stresses in Bi-material Strip Subjected to Constant Temperature Having Longitudinal Hole by Varying Depth and Diameter of Hole

Sr. No.	Variation in hole (mm)		Deflection (mm)	Stresses in N/mm^2			
	Diameter (mm)	Depth (mm)		S_X	S_1	S_2	S_3
1	5	10	0.8505	199.597	320.312	102.842	1361
2		20	0.8505	243.902	317.597	101.747	1358
3		30	0.8505	217.108	318.152	94.815	1358
4		40	0.8505	195.18	299.144	99.229	1358
5		50	0.8504	164.661	321.817	92.026	1412
6	7.5	10	0.8502	207.025	411.248	102.648	1228
7		20	0.8499	209.378	411.084	101.503	1209
8		30	0.8495	189.806	406.988	106.45	1230
9		40	0.8492	176.966	424.139	128.277	1223
10		50	0.8488	166.024	436.52	118.24	1214
11	10	10	0.8496	185.587	379.93	99.57	1212
12		20	0.8487	196.397	374.378	98.191	1213
13		30	0.8476	205.332	367.138	99.359	1239
14		40	0.8466	179.704	373.203	104.384	1228
15		50	0.8457	166.452	435.472	113.069	1220
16	15	10	0.8481	179.617	374.839	99.743	1259
17		20	0.8451	189.507	368.187	100.882	1290
18		30	0.8419	172.786	367.88	99.675	1277
19		40	0.8383	171.899	368.142	99.454	1226
20		50	0.8341	164.612	433.396	139.589	1214

Figure 7: Variation in Stresses with Depth of Hole for 15 mm Diameter Hole 5 Discussion and Conclusion

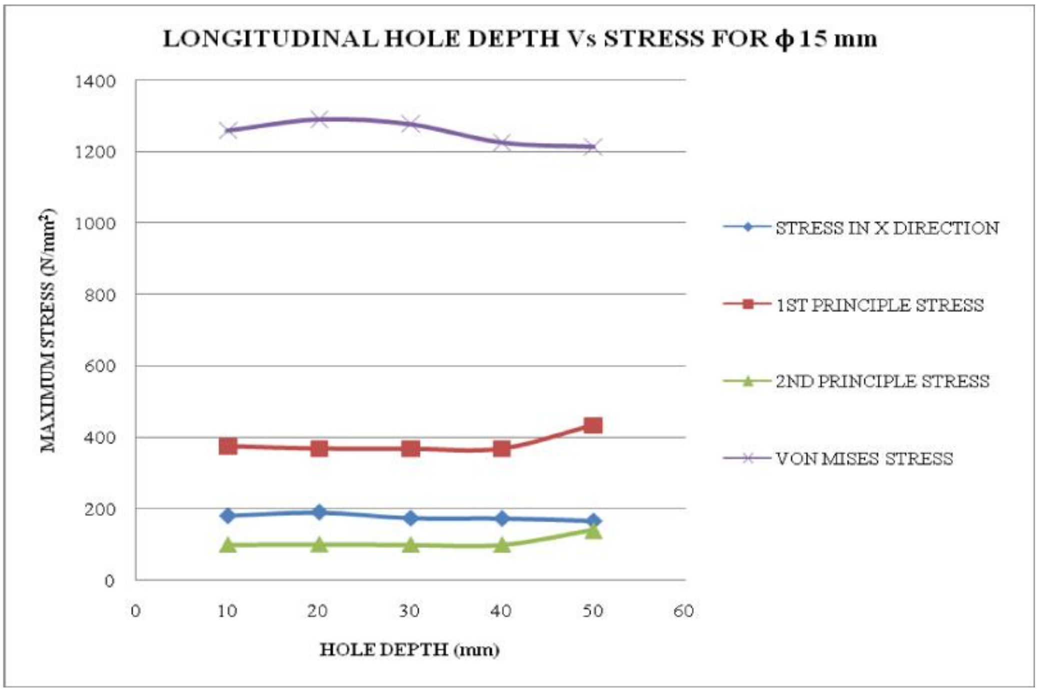


Figure 8: Variation in Stresses with Diameter of Hole for 50 mm Depth Hole

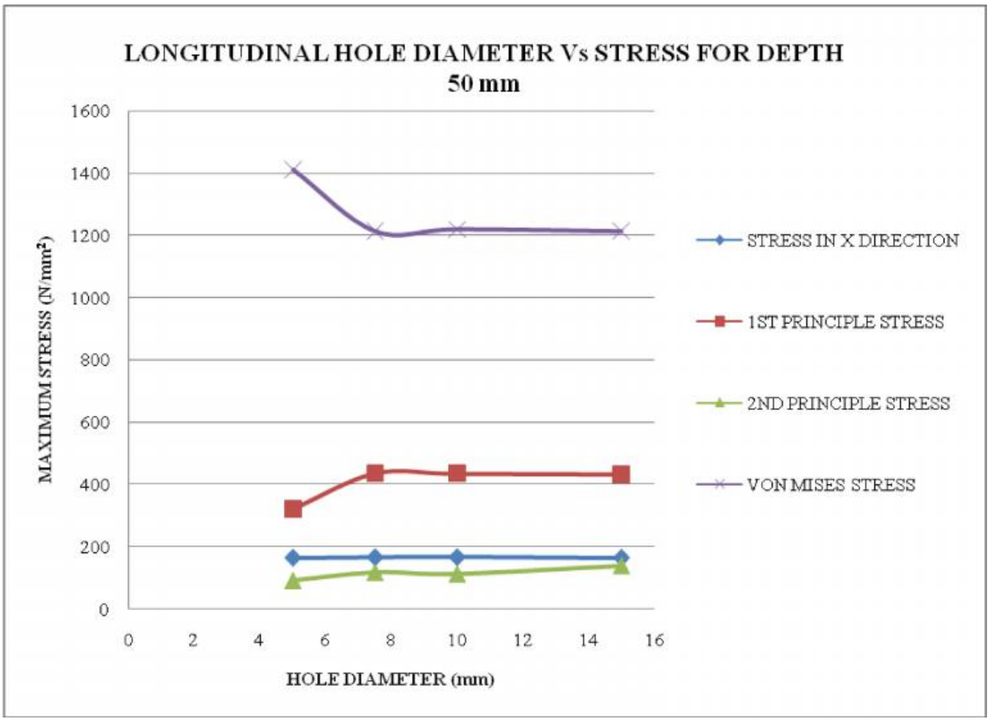


Table 5: Comparison of Stresses in Bi-material Strip Subjected to Axial Temperature Gradient by Varying Diameter and Depth of Longitudinal Hole

Sr. No.	Variation in hole (mm)		Deflection (mm)	Stresses in N/mm^2			
	Diameter (mm)	Depth (mm)		S_X	S_1	S_2	S_3
1	5	10	0.303	83.463	109.132	52.706	94.544
2		20	0.3117	88.488	126.948	52.631	102.628
3		30	0.306	63.42	134.955	52.809	110.799
4		40	0.307	79.737	105.979	52.551	94.968
5		50	0.311	64.621	64.83	49.76	95.908
6	7.5	10	0.308	93.22	121.321	53.498	101.016
7		20	0.307	96.542	121.2	53.601	107.029
8		30	0.303	81.845	117.483	53.467	110.929
9		40	0.304	73.813	99.779	53.373	94.367
10		50	0.306	65.991	66.497	51.909	96.356
11	10	10	0.306	69.214	88.509	53.591	95.231
12		20	0.308	84.185	140.985	53.517	100.982
13		30	0.312	79	117.283	53.547	95.111
14		40	0.305	72.037	116.138	53.558	95.146
15		50	0.309	63.655	65.165	50.999	95.971
16	15	10	0.304	89.721	117.636	52.297	101.433
17		20	0.306	79.692	123.536	53.542	93.294
18		30	0.310	76.917	117.223	53.23	93.819
19		40	0.308	72.865	111.361	53.326	95.097
20		50	0.284	64.4	65.811	53.105	94.779

Figure 9: Variation in Stresses with Depth of Hole for 15 mm Diameter Hole

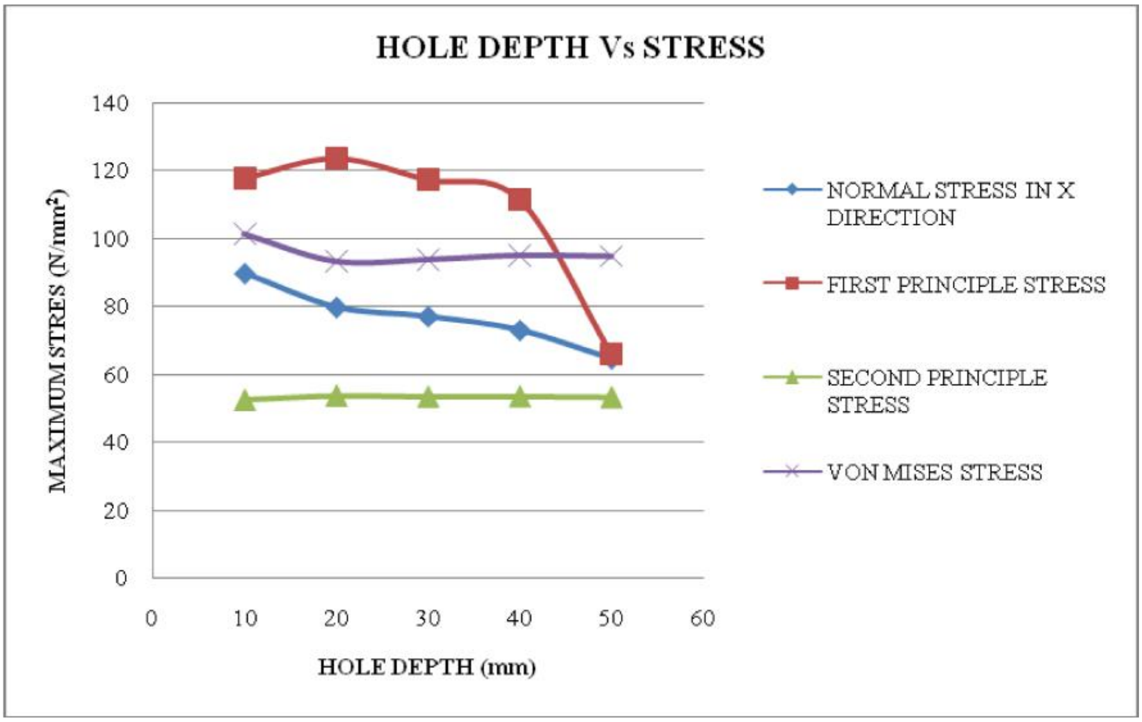
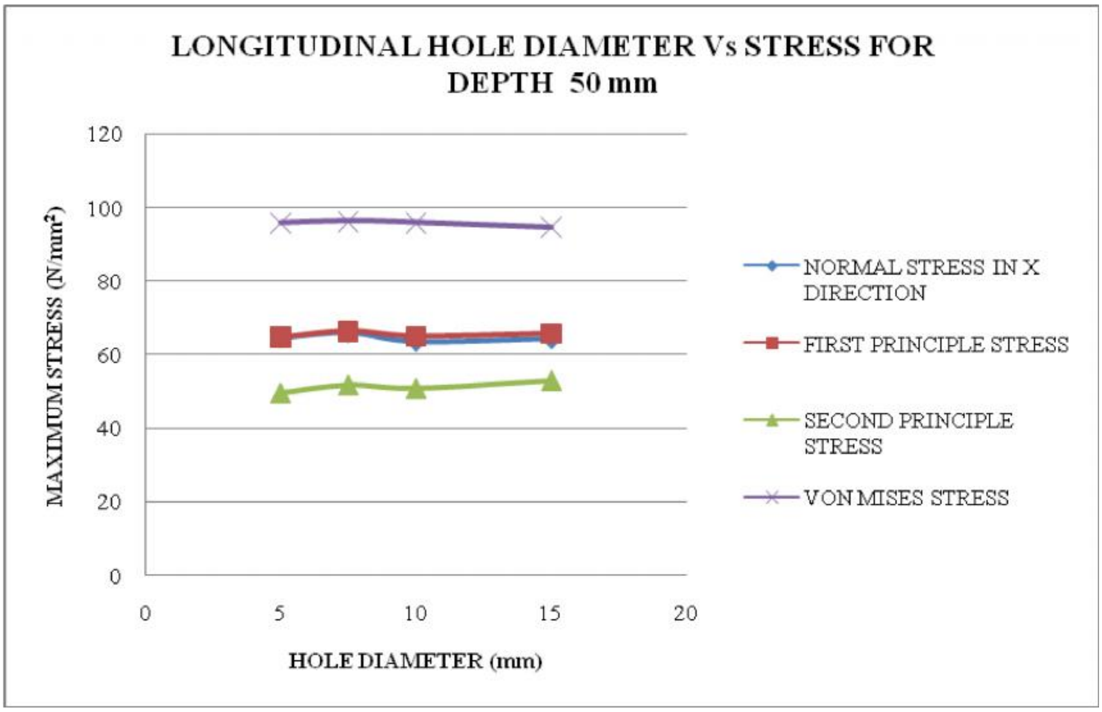


Figure 10: Variation in Stresses with Diameter of Hole for 50 mm Depth Hole



DISCUSSION AND RESULTS

Though the detailed results are presented earlier, here an attempt is made to compare the stresses obtained in bi-material strip with discontinuities subjected to constant temperature and axial temperature gradient. For comparison of stresses first principle stress is considered. The detailed discussion is as follows.

Effect of Discontinuities on Stresses in Bi-material Strip

The discontinuities in the form of transverse hole and longitudinal hole in bi-material strip subjected to constant temperature are considered for analysis.

Effect of Diameter of Transverse Hole on Stresses in Bi-material Strip

The through transverse hole is taken as discontinuity in bi-material strip and its FE analysis is carried out by varying the diameter of hole. The results are tabulated in Table 2. From the table it is observed that as diameter is varied the stresses also vary. The increase in diameter shows significant increase in stresses.

Effect of Diameter of Longitudinal Hole on Stresses in Bi-material Strip

The discontinuity in the form of longitudinal hole is considered for analysis. The total hole area equally divided by upper strip with low coefficient of thermal expansion and lower strip with high coefficient of thermal expansion. The diameter of the hole is varied keeping depth constant for analysis. The results are tabulated in Table 3. From the table it is observed that as diameter varies stresses also vary up to certain limit, further increase in diameter have no significant effect on stresses.

Effect of Depth of Longitudinal Hole on Stresses in Bi-material Strip

The longitudinal hole diameter is kept constant and its depth is varied the result of which is shown in Table 3. From the table it is found that there is no significant change in stresses for variation in depth of hole. Further it is observed that for through hole there is increase in stress as compared to hole depth less than through hole.

Effect of Discontinuities on Stresses in Bi-material Strip Subjected to Axial Temperature Gradient

Further the discontinuities in the form of transverse hole and longitudinal hole in bi-material strip subjected to axial temperature gradient are considered for analysis.

Effect of Diameter of Transverse Hole on Stresses in Bi-material Strip Subjected to Axial Temperature Gradient and its Comparison with Bi-material Strip Subjected to Constant Temperature

The through transverse hole is taken as discontinuity in bi-material strip and its FE analysis is carried out by varying the diameter of hole. The results are tabulated in Table 4. From the table it is observed that as diameter is varied the stresses also vary. The increase in diameter shows significant decrease in stresses while in bi-material strip subjected to constant temperature increase in diameter shows significant increase in stresses.

Effect of Diameter of Longitudinal Hole on Stresses in Bi-material Strip Subjected to Axial Temperature Gradient and its Comparison with Bi-material Strip Subjected to Constant Temperature

The discontinuity in the form of longitudinal hole is considered for analysis. The total hole area equally divided by upper strip with low coefficient of thermal expansion and lower strip with high coefficient of thermal expansion. The diameter of the hole is varied keeping depth constant for analysis. The results are tabulated in Table 5. From the table it is observed that as diameter increases stresses also increases up to certain limit, further increase in diameter deceases the stresses. While in bi-material strip subjected to constant temperature as diameter increases the stresses also increase up to certain limit, further increase in diameter does not have any effect on stresses.

Effect of Depth of Longitudinal Hole on Stresses in Bi-material Strip Subjected to Axial Temperature Gradient and its Comparison with Bi-material Strip Subjected to Constant Temperature

The longitudinal hole diameter is kept constant and its depth is varied the result of which is shown in Table 5. From the table it is found that there is significant change in stresses for variation in depth of hole. As depth increases stresses also increases up to certain limit, further increase in depth deceases the stresses While in bi-material strip subjected to constant temperature there is no significant change in stresses for variation in depth of hole.

CONCLUSION

In case of transverse through hole stresses are directly proportional to size of hole when subjected to constant temperature while stresses are inversely proportional to size of hole in case of axial temperature gradient loading.

In case of longitudinal hole there is no effect of variation in depth for constant temperature loading while when it is subjected to axial temperature gradient, stresses increases up to certain limit and then decreases.

In case of longitudinal hole when diameter is varied for constant temperature loading the stress first increases up to certain limit and then remains constant while for axial temperature gradient the stresses first increases up to certain limit and then decreases.

From this analysis it is seen that the temperature gradient and discontinuities play important role in stress distribution as compared to a simple bi-material strip with constant cross section.

REFERENCES

1. Aleck B J (1949), "Thermal Stresses in a Rectangular Plate Clamped along an Edge", *ASME Journal of Applied Mechanics*, Vol. 16, pp. 118-122.
2. Born J S and Horvay G (1955), "Thermal Stresses in Rectangular Strips–II", *Journal of Applied Mechanics*, Vol. 22, pp. 401-406.
3. Durelli A J and Tsao C H (1955), "Determination of Thermal Stresses in Three-Ply Laminates", *ASME Journal of Applied Mechanics*, Vol. 77, pp. 190-192.
4. Eischen J W and Everett J S (1989), "Thermal Stress Analysis of a Bi-material Strip Subject to an Axial Temperature Gradient", *ASME Journal of Electronic Packaging*, Vol. 111, pp. 282-287.
5. Eischen J W, Chung C and Kim J H (1990), "Realistic Modeling of Edge Effect Stresses in Bi-material Elements", *ASME Journal of Electronic Packaging*, Vol. 112, pp. 16-22.
6. Khurmi R S and Gupta J K (1999), "A Textbook of Machine Design", EPH Publication.
7. Rao Venkateshwara A, Prasad K S V, Avinash M, Nagababu K, Manohar V, Raju P S R and Chandra G R (2012), "A Study on

Deflection of a Bi-metallic Beam Under Thermal Loading Using Finite Element Analysis", *IJEAT Journal*, Vol. 2, pp. 81-82.

8. Sathe Madhulika (2004), "Design, Fabrication and Thermomechanical Testing of a Vertical Bimorph Sensor in the Wafer Plane", pp. 6-44, A Thesis Submitted to Louisiana State University and Agriculture and Mechanical College.

9. Suhir E (1986), "Stresses in Bi-metal Thermostats", *ASME Journal of Applied Mechanics*, Vol. 53, pp. 657-660.

10. Suhir E (1989), "Interfacial Stresses in Bi-metal Thermostats", *ASME Journal of Applied Mechanics*, Vol. 56, No. 3, pp. 595-600.

11. Timoshenko Stephen P and Gere James (2010), "Buckling of a Bi-metallic Strip", *Theory of Elastic Stability*, 2nd Edition, pp. 310-313.