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Research Article

Design of Experimentation of Engine Head Bolt by Finite Element Analysis

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Abstract

This paper represents the design of the engine head bolt by Finite element analysis (FEA). Response surface modeling and analysis of compressive ignited engine head bolt carried out by varying different parameters. Design parameters such as thread radius, total length, thread angle, force, and temperature at various ranges. Simple equation is calculated which gives values of total deformation of compressive ignited engine head bolt by carrying out a regression analysis. It shows that force, thread angle and material property are significant parameters which affect total deformation because their P value near to 0.92. Also, it shows the design parameter effect of deformation of the engine head bolt has been obtained.

Keywords: *Engine head bolt, Response surface modeling, deformation, composite material etc.*

1. Introduction

Bolted joints are one of the most common elements in construction and machine design. They consist of fasteners that capture and join other parts, and are secured with the mating of screw threads. The compression Ignited engine head bolt having most common mode of failure is due to overloading. Operating forces of the application produce loads that exceed the clamp load, causing the joint to loosen over time or fail catastrophically.

Over torque might cause failure by damaging the threads and deforming the fastener, though this can happen over a very long time. Under torque can cause failures by allowing a joint to come loose and it may also allow the joint to flex and thus fail under fatigue. Brinelling may occur with poor quality washers, leading to a loss of clamp load and subsequent failure of the joint. Other modes of failure include corrosion, embedment, and exceeding the shear stress limit.

2. Simulation

Finite element analysis of engine head bolt

Analysis has been carried out in ANSYS work bench. Constrained geometry of the engine head bolt is as shown in figure 1.1.

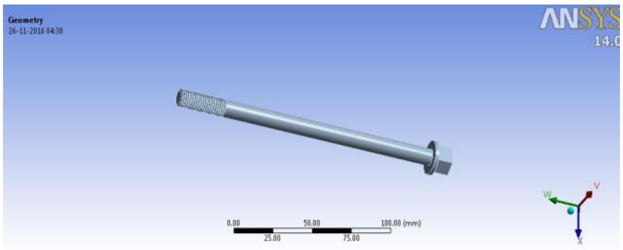

Fig.2.1 Geometry of the bolt in ANSYS

Fig.1.2 shows that the geometry of bolt is meshed by using solid element. Total number of nodes 49208 and elements 27491 are generated after meshing. One end of the bolt is fixed in all direction while load is applied in another end.

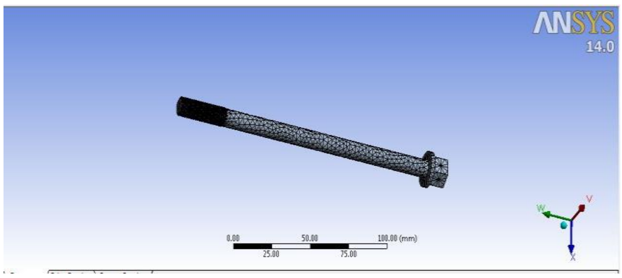

Fig.2.2 Meshed model of engine head bolt

Table No.1.1 shows that the Aluminum Matrix Sic Fiber (17.5%) composite metal matrix material properties is selected from the engine specification requirement as per follows

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Table No.2.1 Material properties of Bolt for analysis

Sr.No	Material Property	Values
1	Density (kg/m3)	2800
2	Young's modulus (Pa)	1.00e11
3	Poisson's ratio	0.22
4	Bulk modulus (Pa)	5.95e10
5	Shear modulus (Pa)	4.09e10
6	Ultimate tensile strength (Pa)	4.616e+8
7	Yield tensile strength (Pa)	4.065e+8
8	Yield comp. strength (Pa)	4.065e+8
9	Coefficient of thermal expansion (1/°C×10^{-6})	14

Table No.2.2 Corresponding parameters according to RSM (Response Surface Modelling)

Sr.No.	P1	P2	P3	P7	P8	P5	P6
1	149.1212	54.11802	4.119818	264.9443	29592.73	0.595255	1139.934
2	157.7194	59.51168	4.021793	258.3032	29018.66	0.61527	1218.365
3	149.6792	55.70533	4.40143	238.7408	31036.18	0.626759	976.4385
4	154.7907	58.40598	4.242438	241.4925	29973.01	0.624008	1117.496
5	131.9644	57.54947	3.912565	266.4022	27742.43	0.49775	927.8082
6	135.58	62.89415	4.295003	247.2307	26926.92	0.495813	957.4723
7	144.0676	60.6398	4.512688	233.9464	27152.41	0.528952	1049.679
8	158.3936	65.03706	3.929235	251.1106	28226.89	0.60087	911.4311
9	140.283	62.03025	3.821967	225.5161	31166.07	0.592667	1187.417
10	142.6046	63.94756	4.479751	270.3668	31984.25	0.617064	1446.358
11	148.2485	60.56134	4.376401	254.8228	31927.2	0.639169	1041.985
12	136.4377	55.64097	4.562373	232.5476	29804.66	0.551768	1315.098
13	132.5122	56.64209	3.99268	272.5	27826.4	0.500743	1028.232
14	155.94	64.16241	4.510396	246.0863	26604.47	0.558297	904.2802
15	152.6734	63.16849	3.807754	244.4476	31545.33	0.648406	1036.967
16	160.4687	54.78512	4.186982	264.9663	30191.04	0.65049	1067.669
17	144.2155	59.37968	4.023478	266.7081	28470.99	0.554806	1268.877
18	151.1215	62.15171	4.105871	236.5765	27144.43	0.55288	1000.732
19	141.665	58.20628	3.901381	227.8357	29302.87	0.562227	1270.166
20	138.2017	65.59567	4.33174	256.2937	30971.42	0.580462	1179.807
21	148.7863	65.97119	3.767004	247.0326	29834.79	0.599324	1264.182
22	134.2455	54.17126	4.211562	257.8139	30891.93	0.56273	1089.27
23	153.2576	59.60686	4.315126	232.3447	31433.7	0.648845	1101.996
24	156.0447	55.59037	4.159218	273.7408	30427.57	0.638643	1273.025
25	138.3603	61.0834	4.557762	251.3462	26563.29	0.498904	1057.34
26	137.3967	62.17072	3.902451	268.0481	28632.67	0.533508	1158.763
27	144.7068	57.4149	3.956585	226.459	27146.66	0.53093	1127.238
28	151.535	58.07879	4.011851	236.0168	28962.86	0.591765	1121.448
29	160.9636	62.85359	4.362881	262.2884	27836.88	0.602558	894.6289
30	140.7004	64.10964	4.453999	243.2682	31720.51	0.604649	1177.957
31	155.5096	58.23349	4.306086	256.9845	26691.79	0.55853	1016.306
32	152.5525	56.24437	3.776942	253.1633	29017.78	0.596172	1289.63
33	136.5402	63.52509	4.053729	228.1196	30319.4	0.561838	1248.532
34	132.3653	55.00231	4.192097	241.1152	27780.65	0.499765	1117.542
35	158.7122	57.02604	4.397346	248.837	31825.21	0.678632	1050.873
36	151.967	65.11317	3.952788	230.6938	28205.59	0.578037	974.2129
37	148.6488	58.92983	4.544701	235.8949	29655.41	0.59483	1056.409
38	143.1115	63.64291	4.447756	272.885	27131.96	0.525611	947.6484
39	144.7667	61.38987	3.897125	266.8779	30869.78	0.604106	1360.887
40	140.4207	60.27452	4.124818	261.7584	31117.61	0.592494	1389.237
41	141.0624	61.22917	3.891098	231.2955	30192	0.576616	1211.342
42	134.4648	58.17288	4.291296	238.6028	32016.46	0.584525	1310.076
43	152.8452	62.64547	4.177137	244.0125	28145.93	0.579313	901.8488
44	152.237	57.2219	4.48534	228.3353	26434.84	0.542197	777.429
45	140.5343	60.83981	4.136523	249.3524	28390.82	0.540583	1289.924
46	145.2147	59.81205	3.994563	270.9988	27087.57	0.531547	1048.794
47	158.1035	56.13542	3.812748	254.6137	30980.54	0.658148	1253.761
48	158.4853	65.53935	4.421408	258.4833	31290.14	0.666294	1025.496
49	147.0521	54.02752	4.593499	265.0111	29650.55	0.588822	1066.481
50	137.6982	64.27583	4.010399	262.8771	29100.46	0.543437	925.1188

51	153.9449	62.06073	3.986306	273.7326	29549.28	0.612944	904.9875
52	156.9775	54.55229	4.41073	261.9411	27413.1	0.57879	942.6765
53	143.9357	59.99305	4.589466	243.6204	28573.07	0.555919	986.022
54	140.8886	63.05483	4.083594	237.3483	26540.03	0.506603	1042.806
55	152.2359	56.70674	4.12285	227.0305	31724.77	0.650486	1024.889
56	135.4342	60.94513	3.911477	248.5502	27968.89	0.514378	1108.173
57	133.0315	56.00557	4.281729	254.9469	30150.29	0.545085	1001.212
58	147.1384	58.48783	3.784858	256.8256	30538.15	0.60661	1178.369
59	138.3457	64.31881	4.461243	267.2525	31542	0.591987	1055.114
60	160.639	65.66412	4.239269	234.6363	29245.7	0.631282	1197.184
61	132.2402	65.04582	4.247	257.2642	27405.56	0.492549	1064.493
62	136.0951	58.17916	4.464921	262.7362	28989.04	0.535576	1088.398
63	153.8936	62.98892	4.575373	231.7649	30158.86	0.625049	1339.586
64	141.767	57.13644	3.922864	236.551	29908.52	0.574351	1128.632
65	145.7687	55.64686	4.036151	248.287	26928.71	0.530205	1044.549
66	159.2674	61.1415	4.275542	271.4136	28622.31	0.613081	914.0388
67	151.3902	59.37288	3.807137	266.8518	31195.65	0.636898	1026.614
68	147.0665	54.41851	4.356002	244.605	30704.58	0.609782	955.5727
69	156.6605	61.63907	3.949441	227.2955	28004.94	0.590302	1004.931
70	138.0044	63.93182	4.100436	252.1667	31852.58	0.595825	1010.069
71	155.9486	55.23448	4.120167	240.3435	27447.12	0.575671	893.7658
72	133.4058	59.19917	3.938626	253.2439	28876.21	0.523154	918.3957
73	159.3734	60.42202	3.878969	238.0182	32256.31	0.691289	1176.375
74	140.4794	62.72935	4.270048	265.6901	31424.12	0.598572	1249.872
75	154.9857	58.05715	4.450188	273.9779	27912.75	0.582205	1040.942
76	142.1449	54.68441	4.065498	263.4347	30069.85	0.578714	1043.452
77	147.5122	62.11699	4.411	245.16	30526.03	0.608067	1319.429
78	151.4036	64.39214	4.516486	230.1647	28262.86	0.576879	1008.814
79	137.6653	57.52656	4.230318	227.2772	29591.87	0.552693	1256.699

Table No1.2 shows that the relation between the numbers of input parameters and gives deformation and stress to build a response surface modeling. A Design of Experiments, or DOE, the method required many design points should be solved. Once the required solutions are complete a response surface is fitted through the results, allowing designs to be queried where no hard solution exists. In this table, P1 – Total Length, P2 – Angle of Thread, P3 – Thread Radius, P7 – Temperature (^{0}C), P8 - Force Magnitude (N), P5 - Total Deformation Maximum (mm), P6 - Equivalent Stress Maximum (MPa).

As shown in the table No.1.2. Regression analysis of engine head bolt is carried out by using M S excels 2007 for obtaining regression equation. Regression analysis of engine head bolt has been done by using MS excel and following equation of regression is obtained.

P5=-0.5383+0.003702(P1)-5.9E-06(P2)-0.00109(P3) +3.18E-06(P7) +1.98E-05(P8) .... (1)

3. Results and discussion

In this paper, analysis of engine head bolt by using the response surface modelling has been discussed. This analysis provides the resulting graphs of design parameters Vs total deformation. Under the loading condition, total deformation of engine head bolt is obtained. Total deformation of engine head bolt is as shown below in figure 1.3.In this case, static analysis is done by using the finite element analysis, in the figure blue color indicates the minimum deformation 0.06449 mm acting on the bolt and Red color indicates maximum deformation 0.5804 mm.

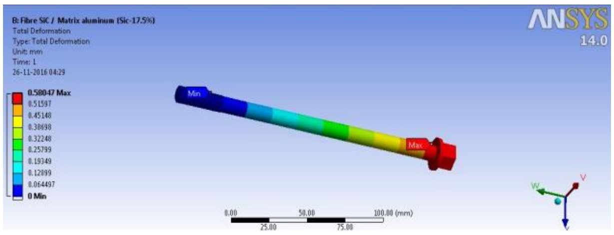

Fig.3.1. Total deformation of engine head bolt

3.1 Angle Vs Total Deformation

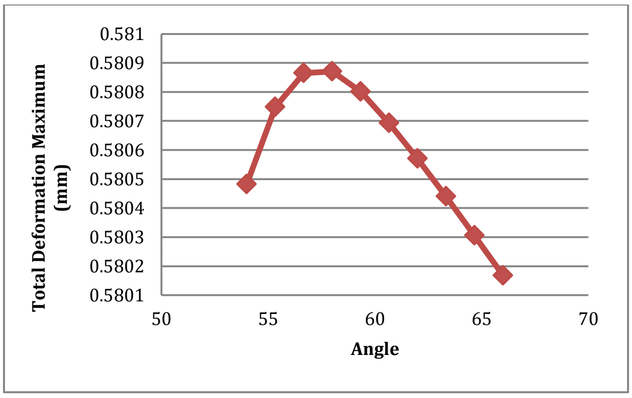

Fig.3.1. Angle Vs Total Deformation Maximum (mm)

Figure shows relationship between angles Vs Total deformation. In this case, when angle increases total deformation of bolt increases up to 59^0 and after that it decreases when increases in angle where maximum total deformation is 0.580801 mm.

3.2 Force Magnitude (N) VS Total Deformation (mm)

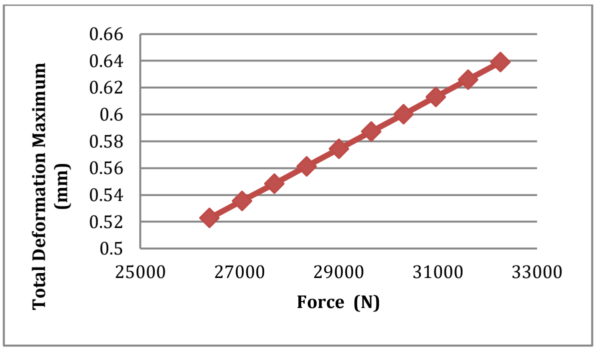

Fig.3.1. Force (N) Vs Total Deformation (mm)

Figure shows relationship between Force Vs Total deformations. In this case, when force magnitude increases total deformation of bolt increases up to 32263 N and after that it decreases because stress exceeds elastic limit.

3.3 Total Length (mm) Vs Total Deformation (mm)

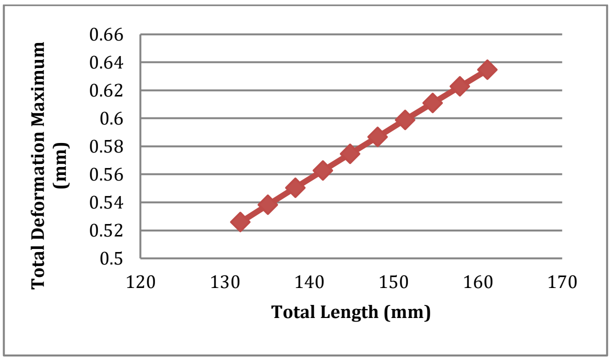

Fig.3.3. Total Length (mm) Vs Total Deformation (mm)

Figure shows relationship between Total Length Vs Total deformations. In this case, when bolt Length increases total deformation of bolt increases up to 0.6345808 mm and after that it deformation increases because increasing the length.

3.2 Force Magnitude (N) VS Total Deformation (mm)

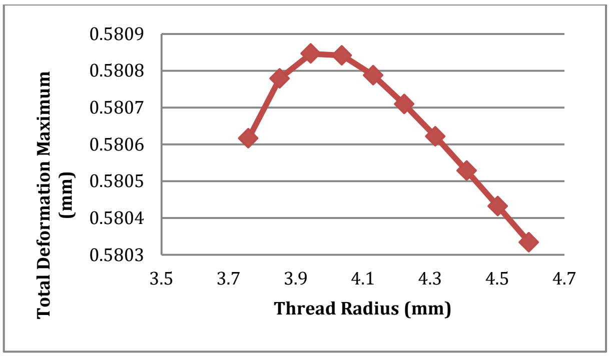

Fig.3.1. Thread Radius (mm) Vs Total Deformation (mm)

Figure shows relationship between Thread Radius Vs Total deformations. In this case, when Thread Radius increases total deformation of bolt increases up to 0.580846 mm and after that it decreases because increasing the diameter of bolt.

Conclusions

1) Finite element analysis has been carried out in engine head bolt.
2) It is observed that thread angle and material property are significant parameters which affect total deformation because their P value is 0.92.
3) Relationship among design parameters and total deformation has been obtained.
4) Simple equations find out which gives value of total deformation of engine head bolt by carrying regression analysis in M S office 2007.

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