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Design and Analysis of Poppet Engine Valve for Enhanced Mechanical Properties with Varied Geometric Parameters and Materials

Vidyadhar.C.Kale[1], Sagar.S.Deshpande[2]
*M.E (Metallurgical Engineering); M.Eng(Canada)
Department of Mechanical Engineering, Gokhale Education Society's R. H. Sapat College of Engineering, Management Studies and Research, Nashik,India.
M.E Student;Mechanical Design

Abstract

Poppet engine valve is a precision engine component which blocks gas flow ports and controls the exchange of gases in internal combustion engines. The functionality of the valve is to seal the working space inside the cylinder against manifolds by continuously opening and closing of valve according to valve timing diagram. Existing difficulties with poppet engine valve being that it tend to fail due to fatigue after executing about 300 million operating cycles. Thus this research paper aims to establish effect of varied materials and Geometric parameters on mechanical properties of poppet engine valve to improve its performance over life and fatigue life using Ansys software.

Keywords: Poppet engine valve, Geometric parameters, Fatigue life, Mechanical properties, Materials.

Introduction

Design of poppet engine valve intrinsically affects the performance of internal combustion engine. With this view this research paper aims to explore the effect of variation of geometric parameters and materials on the mechanical properties of poppet engine valve with mainly to improve its fatigue life.Both exhaust and inlet valve are vital components of an IC engine and which are controlling the flow of fresh air and burnt gases in and out of engine cylinders. In four stroke engine during suction stroke inlet valve remains in open condition which allows the flow of fresh air insidethe combustion chamber and exhaust valve is kept closed. In power stroke both valves remain closed. At the end of power stroke exhaust valve gets opened to remove burnt gases from combustion chamber.

Basic terminology of Poppet engine valve,

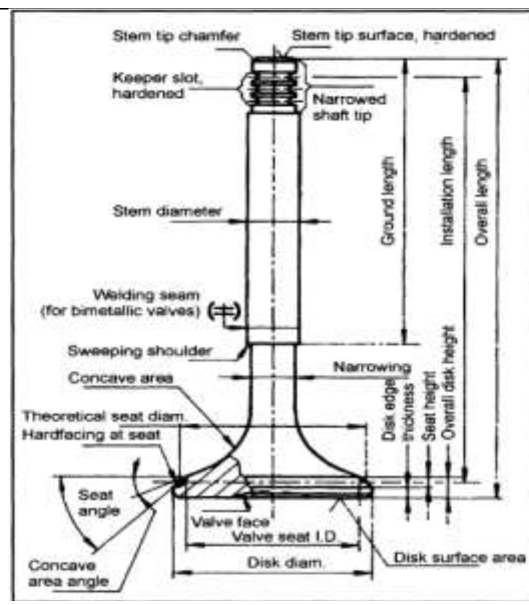

Figure1: Basic terminology of popet valve.[1]

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Design of poppet engine valve

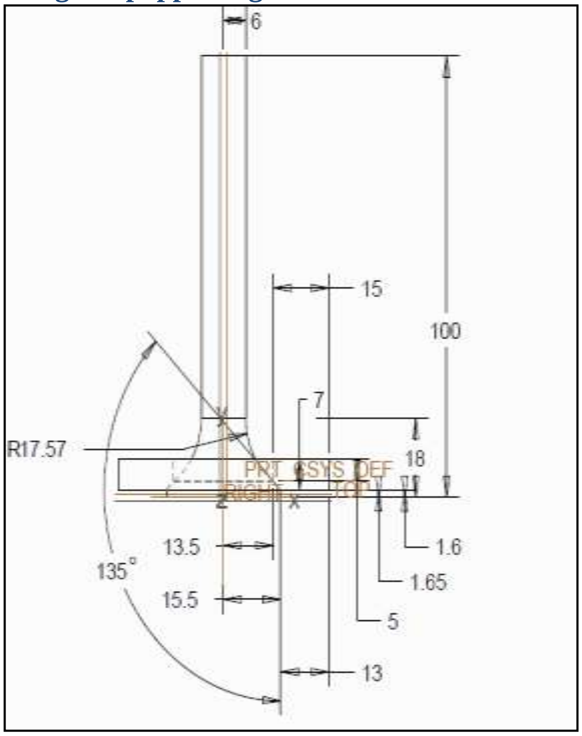

Figure2: Dimensions of poppet valve and valve seat Above figure shows poppet engine valve where all dimension are in mm.

Specification of Engine for which the poppet valve is designed,
Bore Diameter D = 73.5 mm
Length of stroke L = 73.5 mm
Engine Speed N = 5500 rpm
Break horse power (bhp) @ 5500 rpm = 37
Specification of Poppet engine valve
Diameter of valve port (D_p) = 27 mm
Width of valve (W) = 2mm
Valve angle (θ) = 45
Diameter of valve head (D_v) = 31 mm
Thickness of valve disk (t) = 2 mm
Margin (M) = 1.6 mm
Diameter of valve stem (D_s) = 12 mm
Maximum valve lift (h_{max}) = 10 mm

Kinematic motion of poppet engine valve is governed by valve actuating mechanism generally push rod mechanism. This mechanism is driven by motion of crankshaft of engine and as a result of which poppet engine valve continuously open and closes the ports which control the flow of gas through ports.

Poppet engine valve is opened by valve actuating mechanism just before the beginning of exhaust stroke so that exhaust gases are blown out and it is closed by compressed spring just after the beginning of suction stroke. Thus poppet engine valve is continuously under tension and compression alternatively which lead to fatigue failure
alternatively which lead to fatigue failure.

Calculation for forces acting on poppet engine valve, [4]

a) Force required to open the valve

$F_{open} = F_i + F_l + F_g$ -------------(1)

Where,
$F_i =$ Initial spring force
$F_l =$ Force required to lift the valve
$F_g =$ Gas force

Mathematically,

$F_i = \frac{\pi}{4} D_v^2 * P_s$ ------------------(2)

Where,
P_s = Suction pressure
= 0.002 to 0.004 N/mm^2

$F_l = k * h_{max}$ -----------------(3)

Where K= spring stiffness
= 10 N/ mm

$F_g = \frac{\pi}{4} D_v^2 * P_g$ ------------------(4)

Where P_g = gas pressure
= 0.35 to 0.45 N/mm^2

Substituting equation (2),(3) and (4) in equation (1),

F_{open} = 379.11 N
F_l = 15.08 N

Calculation for valve timing of poppet engine valve. [4]

Engine under consideration is high speed engine and as a result of which the exhaust valve will open 55 before Bottom dead center and will close 20 after top dead center [3]. This being true theoretically but will deviate from it under practical situation whose consideration is beyond the scope of this research paper.

Total angle of rotation of crank shaft when exhaust valve is open is,

$\Theta_1 = 55 + 180 + 20$
$= 255$

Total angle of rotation of camshaft when exhaust valve is open

$\Theta_1 = \frac{255}{2}$
= 127.5
= 2.224 radians

Speed of camshaft is given by,

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$N_{cs} = \frac{5500}{2}$

$= 2750$ rpm

Number of rotation of camshaft per second,

$N_{ps} = \frac{Ncs}{60}$

$= \frac{2750}{60}$

$= 45.83$ seconds

Time required by camshaft to complete one rotation,

$T_{1r} = \frac{1}{Nps}$

$= \frac{1}{45.83}$

$= 0.0218$ sec

Time required by camshaft to complete rotation of one degree,

$T_{1d} = \frac{T\ 1r}{360}$

$= \frac{0.0218}{360}$

$= 6.06*10^{-5}$ seconds

Time for which the exhaust valve is open is given by,

$T_{open} = \Theta_1 * T_{1d} = 255 * 6.06*10^{-5}$

$= 15.453*10^{-3}$ seconds

Cycle time for poppet engine valve to once open and close is given by,

$T_{total} = 360 * T_{1d}$

$= 360 * 6.06*10^{-5}$ seconds

$= 21.86*10^{-3}$ seconds

Where ,

$T_{total} = T_{open} + T_{idle}$

Where,

T_{idle} = Time for which valve is closed and is in idle state which means that it neither opens nor close during this time.

Therefore,

$T_{idle} = T_{total} - T_{open}$

Substituting values in above equation we get,

$T_{idle} = 21.86*10^{-3} - 15.453*10^{-3}$

$= 6.416*10^{-3}$ seconds.

Based on above calculation the condition of poppet engine valve with change in time for 360 rotation of camshaft is given as follows,

Table1: Poppet valve condition with time.

Sr.no	**Span of time (seconds)**	**Poppet Engine valve condition**
1.	0 to $6.41*10^{-3}$	Valve is Idle
2.	$6.41*10^{-3}$ to $9.918*10^{-3}$	Valve opens
3.	$9.918*10^{-3}$ to $18.398*10^{-3}$	Valve is open and Idle
4.	$18.398*10^{-3}$ to $21.86*10^{-3}$	Valve closes

Based on calculation of various forces acting on poppet engine valve, its condition with time and magnitude of forces acting on it is given as follows,

Table2:Forces on Poppet valve with time.

Sr.no	**Span of time (seconds)**	**Poppet Engine valve condition**	**Magnitude of force acting on valve stem head (Newton)**
1.	0 to $6.41*10^{-3}$	Valve is Idle	0
2.	$6.41*10^{-3}$ to $9.918*10^{-3}$	Valve opens	379.11
3.	$9.918*10^{-3}$ to $18.398*10^{-3}$	Valve is open and Idle	379.11
4.	$18.398*10^{-3}$ to $21.86*10^{-3}$	Valve closes	15.08

When poppet engine valve opens nature of force acting on its valve stem is compressive in nature and time during which it closes nature of force is tensile in nature, which leads to fatigue loading of poppet engine valve. This loading of poppet engine valve is unidirectional in nature.

Maximum valve lift is calculated to be 10 mm which corresponds to unidirectional displacement of poppet engine valve during lift to be 10mm so that it opens the port in one direction and displacement to be 10mm during fall so that it closes the port in opposite direction.

Consider the unidirectional displacement of poppet engine valve in following table.

Table1: Displcaement of Poppet valve with time.

Sr.no	**Span of time (seconds)**	**Poppet Engine valve condition**	**Magnitude of Displacement of poppet engine valve (mm)**
1.	0 to $6.41*10^{-3}$	Valve is Idle	0
2.	$6.41*10^{-3}$ to $9.918*10^{-3}$	Valve opens	10

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3.	$9.918*10^{-3}$ to $18.398*10^{-3}$	Valve is open and Idle	0
4.	$18.398*10^{-3}$ to $21.86*10^{-3}$	Valve closes	10

With a view to analyze the effect of Geometric parameters and materials on mechanical properties of poppet engine valve, specially to improve fatigue strength following geometric parameters and materials are considered for purpose of analysis which form the scope of this research paper.

Geometric parameters under consideration,

a) Valve angle
b) Diameter of valve head
c) Thickness of valve disk

Materials selected under consideration,

a) Inconel 625
b) Ti-4.5Al-3V-2Fe-2Moz
c) Ni - Cr - Mo Steel SAE8640_361_QT

Range of magnitude of geometric parameters selected are such that they lie on higher side and some on lower side of designed value,

Range of magnitude of geometric parameters is as follows,

Table 4:Range of geometric parameters.

Sr. no	Geometric parameter	Range of magnitude
1.	Valve angle	30,34,38,40,42,45.
2.	Diameter of valve head	22mm,25mm,28mm,34mm,37mm, 40mm.
3.	Thickness of valve disk	1mm,2mm,3mm,4mm,5mm,6mm.

Transient structural analysis was performed on Ansys Workbench 14.5 on poppet engine valve with above mentioned variation of geometric parameters and materials. In order to analyze the effect of these variation on mechanical properties of poppet engine valve other geometric parameters other than one under consideration is held same for purpose of comparison.

Results and discussion

Transient structural analysis was used in Ansys workbench 14.5 to obtain following results,

Table5: variation of Equivalent elastic stain and Equivalent stress with variation of diameter of valve head for material under consideration.

Material	Diamter of valve head(mm)	Equivalent Elastic strain(mm/mm)	Equivalent stress(Mpa)
Inconel 625	22	0.00011607	21.865
	25	0.000131	24.794
	28	0.00012379	24.441
	31	**0.00013111**	**26.085**
	34	0.00011723	22.697
	37	0.00012573	23.446
	40	0.00012278	23.285
Ti-4.5Al-3V-2Fe-2Mo	22	0.00010658	11.492
	25	0.00012019	13.019
	28	0.00011221	12.632
	31	**0.00011888**	**13.46**
	34	0.00010643	11.775
	37	0.00011463	12.23
	40	0.00011156	12.115
Ni - Cr - Mo Steel SAE8640_361_QT	22	0.00010793	20.347
	25	0.00012182	23.072
	28	0.000011511	22.744
	31	**0.00012192**	**24.273**

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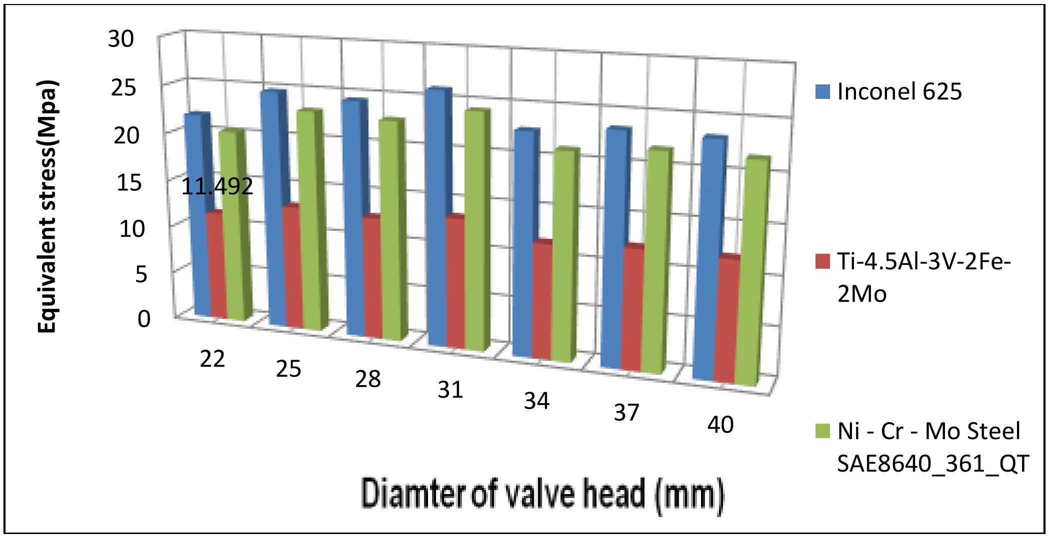
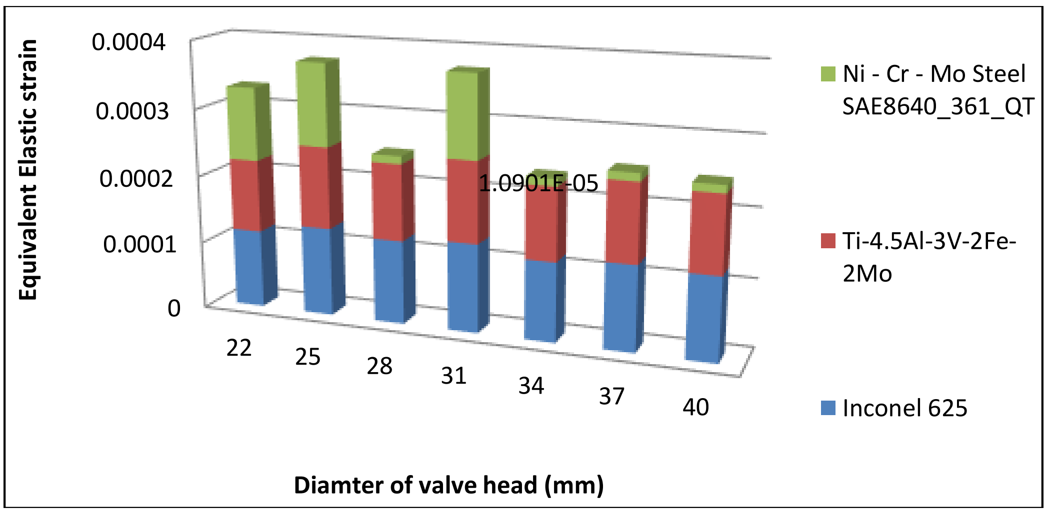
	34	0.000010901	21.121
	37	0.000011691	21.818
	40	0.000011417	21.669

Consider graphical representation of above results,





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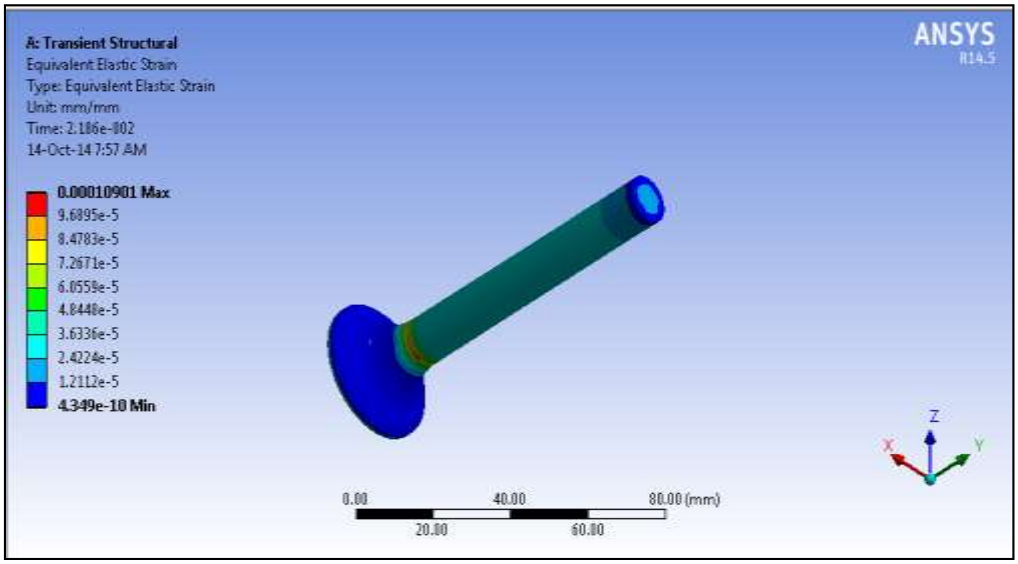

Figure 3: shows Equivalent elastic strain for poppet engine valve of Ni - Cr - Mo Steel SAE8640_361_QT for 34 mm valve head diameter.

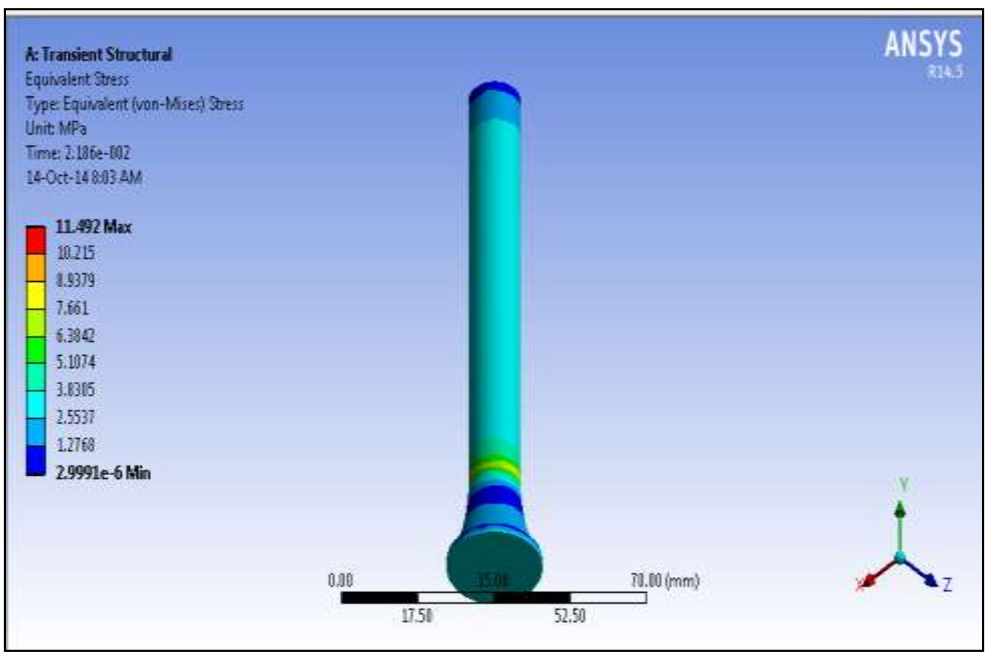

Figure 4: shows Equivalent stress for poppet engine valve of Ti-4.5Al-3V-2Fe-2Mo for 22 mm valve head diameter.

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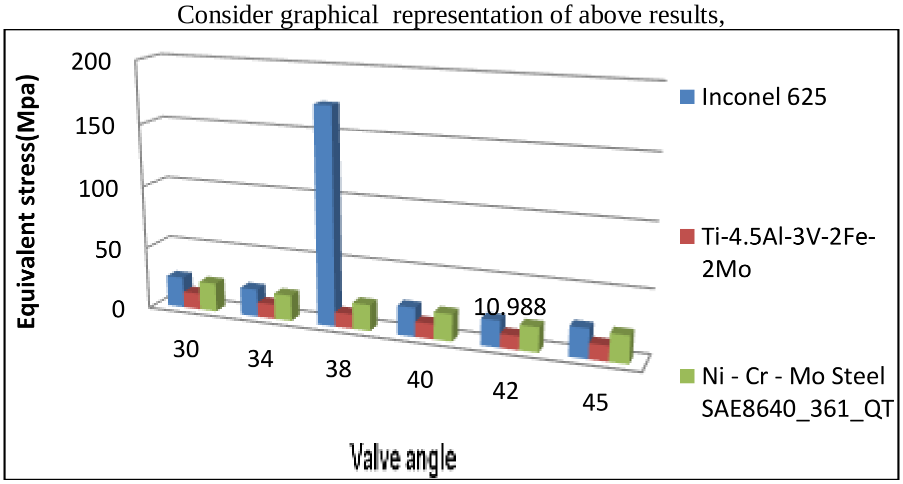
Table 6: the variation of Equivalent elastic stain and Equivalent stress with variation of Valve angle for material under consideration.

Material	Valve angle	Equivalent Elastic strain(mm/mm)	Equivalent stress(Mpa)
Inconel 625	30	0.0001303	24.81
	34	0.00011733	22.286
	38	0.00089712	172.68
	40	0.000125	23.077
	42	0.000010929	21.117
	45	**0.000012526**	**23.337**
Ti-4.5Al-3V-2Fe-2Mo	30	0.000011931	13.006
	34	0.00010711	11.65
	38	0.0001039	11.599
	40	0.00011429	12.059
	42	1.94E-05	10.988
	45	**0.00011465**	**12.22**
Ni - Cr - Mo Steel SAE8640_361_QT	30	0.00012116	23.087
	34	0.0001091	20.739
	38	0.00010677	20.856
	40	0.000011623	21.475
	42	0.00010163	19.65
	45	**0.00011647**	**21.717**

Consider graphical representation of above results,



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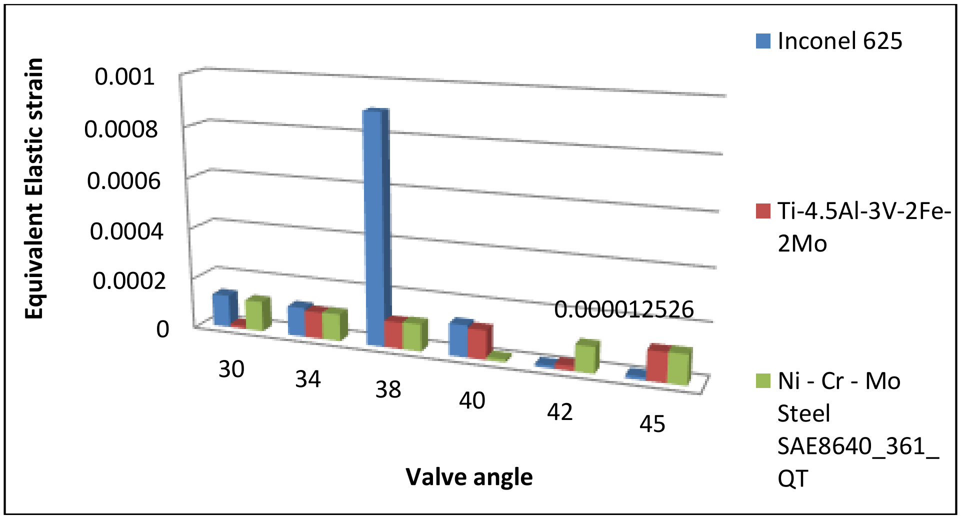

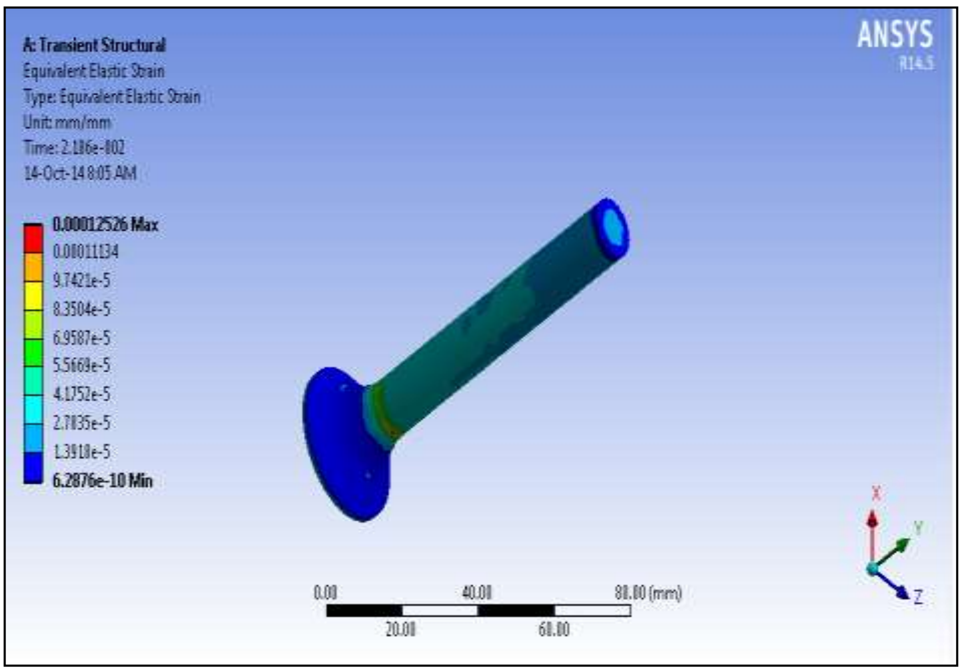

Figure 5: shows Equivalent elastic strain for poppet engine valve of Inconel 625 for 45 degree valve angle.

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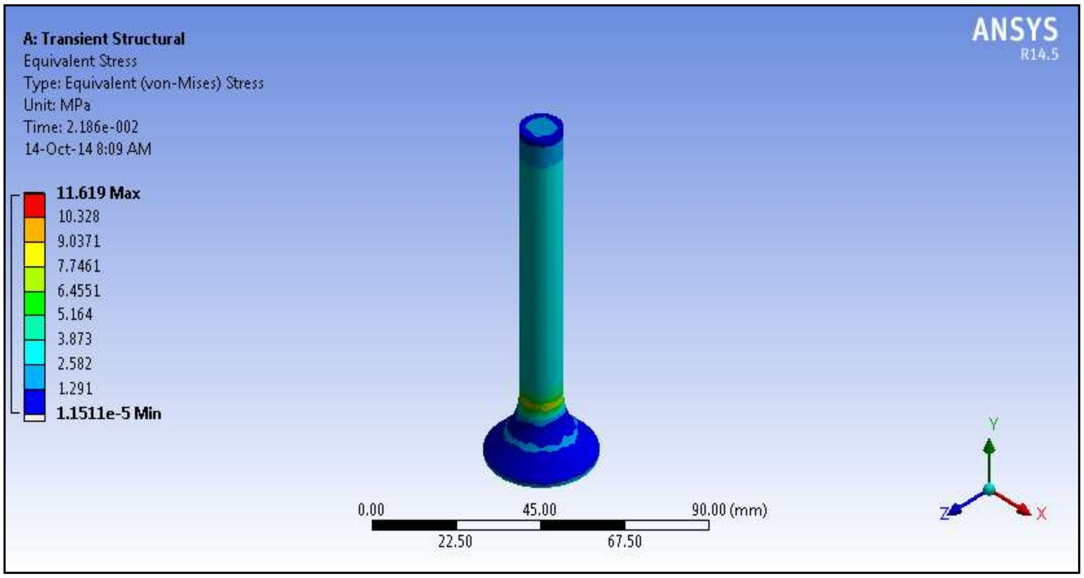

Figure 6: shows Equivalent stress for poppet engine valve of Ti-4.5Al-3V-2Fe-2Mo for 42 degree valve angle.

Table 7: illustrate the variation of Equivalent elastic stain and Equivalent stress with variation of Thickness of valve disk for material under consideration.

Material	Thickness of valve disk(mm)	Equivalent Elastic strain(mm/mm)	Equivalent stress(Mpa)
Inconel 625	1	0.00010658	20.47
	2	**0.00012526**	**23.337**
	3	0.00011973	23.093
	4	0.00011998	23.125
	5	0.00012139	23.5
	6	0.00011717	22.251
Ti-4.5Al-3V-2Fe-2Mo	1	9.72E-05	10.689
	2	**0.00011465**	**12.22**
	3	0.00011097	11.933
	4	0.00010844	11.981
	5	1.10E-04	12.175
	6	1.07E-04	11.619
Ni - Cr - Mo Steel SAE8640_361_QT	1	9.91E-05	13.049
	2	**0.00011647**	**21.717**
	3	0.0001131	21.276
	4	0.0001091	20.739
	5	0.00011287	21.868
	6	0.000010895	20.706

Consider graphical representation of above results,

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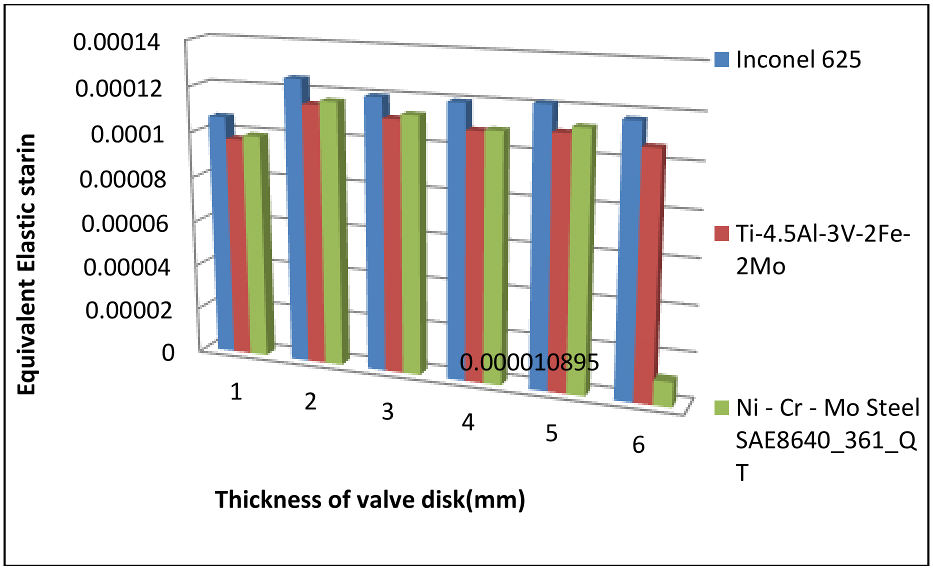
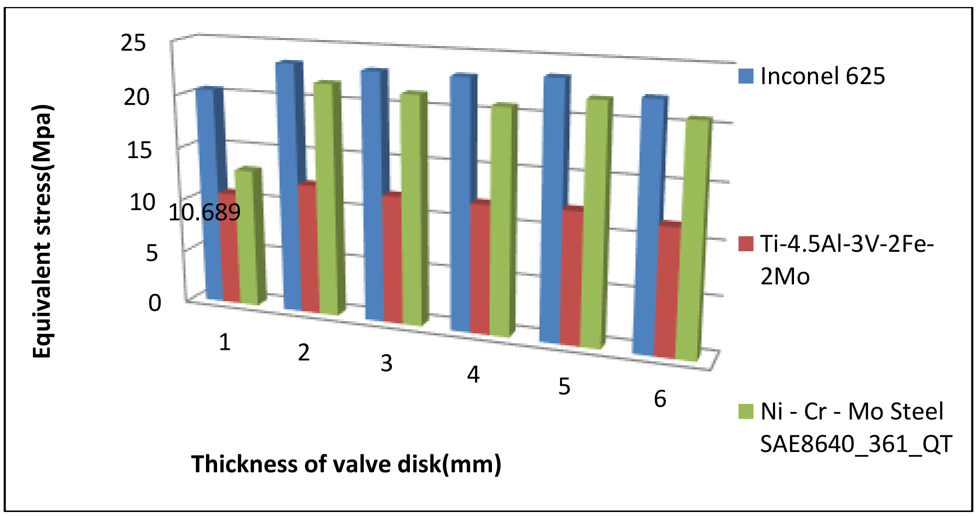
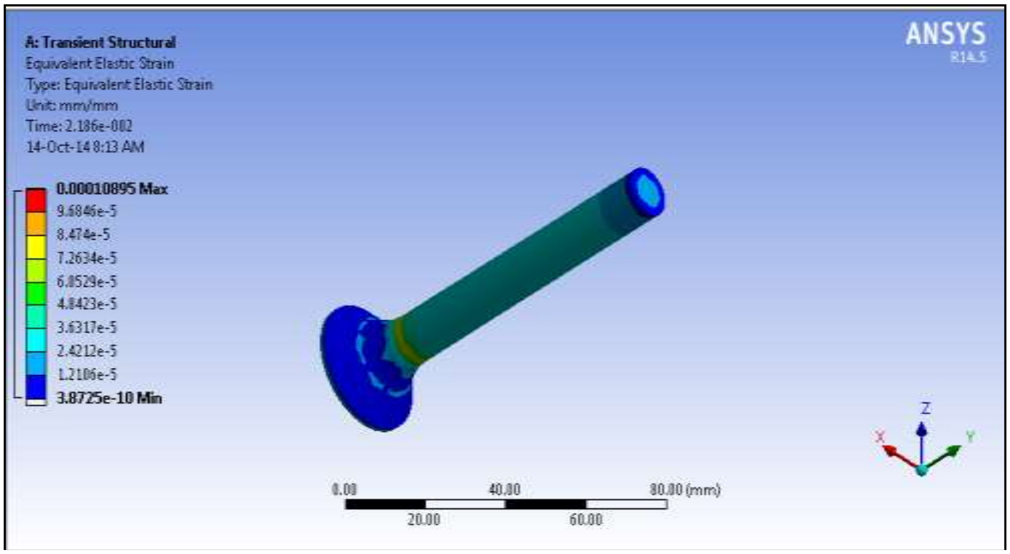


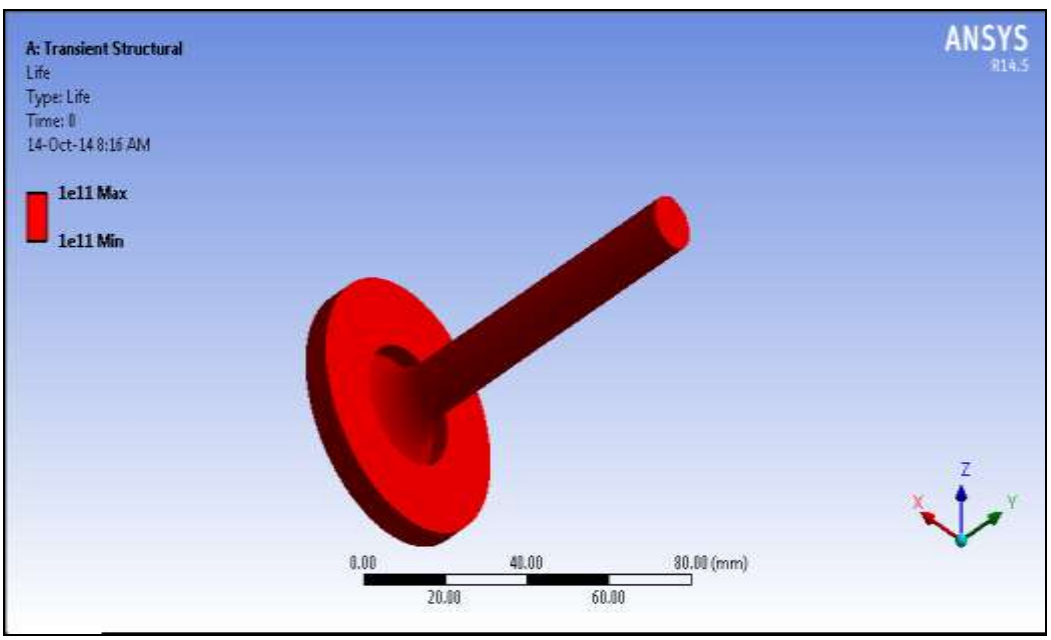




Above figure shows Equivalent stress for poppet engine valve of Ni - Cr - Mo Steel SAE8640_361_QT for 6 mm valve disk thickness.

Table 8: the variation of fatigue life with variation of geometric parameter and materials,

Material	Fatigue life
Inconel 625	1.00E+06
Ti-4.5Al-3V-2Fe-2Mo	1.00E+07
Ni - Cr - Mo Steel SAE8640_361_QT	1.00E+11



Above figure shows fatigue life of Ni - Cr - Mo Steel SAE8640_361_QT.

Conclusion

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Based on results obtained by transient structural analysis following conclusion are deduced,

a. Equivalent elastic strain unequally and uniformly reduces on both sides of designed magnitude for diameter of valve head, which being true for all materials under consideration. Least equivalent elastic strain is obtained for Ni - Cr - Mo Steel SAE8640_361_QT as 0.000010901 for 34 mm valve head diameter which most desirous.

b. Equivalent stress unequally and uniformly increases sides of designed magnitude for diameter of valve head, which being true for all materials under consideration. Least equivalent stress is obtained for Ti-4.5Al-3V-2Fe-2Mo as 11.492 MPa for 22 mm valve head diameter which most desirous.

c. Equivalent elastic strain unequally and non uniformly increases as valve angle decreases below 45 degree, which being true for all materials under consideration. Least equivalent elastic strain is obtained for Inconel 625 as 0.000012526 for 45 degree.

d. Equivalent stress unequally and non uniformly decreases initially and then again increases as valve angle decreases below 45 degree, which being true for all materials under consideration. Least equivalent stress is obtained for Ti-4.5Al-3V-2Fe-2Mo as 10.988 MPa at 42 degree valve angle.

e. Equivalent elastic strain unequally and non uniformly decreases as thickness of valve disk increases above 2 mm, which being true for all materials under consideration. Least equivalent elastic strain is obtained for Ni - Cr - Mo Steel SAE8640_361_QT as 0.000010895 at 6 mm valve disk thickness.

f. Fatigue life remains almost unaffected by change in geometrical parameters but is altered by change in material. It is evident from above result that Ni - Cr - Mo Steel SAE8640_361_QT has highest fatigue for all values of geometrical parameters as 1.00E+11 which is most desirous.

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