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DESIGN AND STRUCTURAL ANALYSIS OF EXHAUST ENGINE VALVE WITH HIGH ENTROPY ALLOYS

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Abstract:- High Entropy Alloys (HEAs) are a new class of alloys, unlike traditional alloys with one or two major elements and remaining elements are minor elements (added to obtain very specific property), containing four, five and even more (up to 20) elements nearly in equimolar proportions. All over the world, an intensive research is going on the design and fabrication of these HEAs as the initial studies indicate that these materials possess far superior properties in terms of high temperature strength, (even specific strength), hardness, ductility, oxidation resistance, creep strength and fatigue strength. Therefore it is but naturally to carry on research whether HEAs could be effectively used to replace traditional alloys like nimonic alloys. In the project, it is planned to design automobile engine valve, using HEAs and compared with the traditional valves made out of nimonic alloys taking all considerations and the warming up of the environmental from the green gasses and thus maintaining eco-friendly environment

Key Words: High entropy alloys, Nimonic alloy, Automobile engine exhaust valve, CREO, ANSYS and Environment.

1. INTRODUCTION

High Entropy Alloys are multicomponent components initially proposed by Yeh and Huang in 1995[1]. HEA's are newly discovered class of metal alloy, composed of at least five elements with the concentration of each element between 5 to 35 atomic percentages (%). HEAs is composed of at least five elements with equal or non-equal composition as be taken. The many researchers are had attention in the high entropy alloys [1]. Day by day the research work is carried out by in many ways. In this project CoCrFeMnNi materials are consider the case study and many researches are carried out using taken HEAs material. The CoCrFeMnNi have the good mechanical propes and thermal properties. CoCrFeMnNi improve its strength with lowering temperature and increasing the strain rate [2].

Thermodynamically, a system reaches equilibrium when the Gibbs free energy of the system ΔG_{mix} reaches its global minimum. The mixing energy of a system is described by equation (1)

$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$$

In which ΔH_{mix} is the enthalpy of mixing, T is the temperature, and ΔS_{mix} is the entropy of mixing. The tendency to form multi-element solid-solution phases is likely using the Boltzmann Hypothesis with the entropy of mixing, ΔS_{mix}, given in equation 2,

Where k is Boltzmann's constant, w is the number of ways of mixing, R is the gas constant, and n is the number of elements. Because there are multiple principal elements, they can be considered solute atoms. Elements with small atomic-size differences are easily interchangeable and able to sit on lattice sites forming solid solutions. Moreover, the enthalpy of mixing of the elements does not favor the formation of compounds. The resulting high entropy of mixing acts to lower the free energy of solution phases. This trend is accompanied by sluggish diffusion due to the difficult cooperation among the migrations of various elements. Coupled with the severe lattice distortions due to multiple solute atoms, diffusion rates are slower in HEAs. Thus, simple solid solutions and nanostructures that avoid the problems of difficult analyses and processing are formed. Figure 1 gives an example schematic of an HEA solid solution.

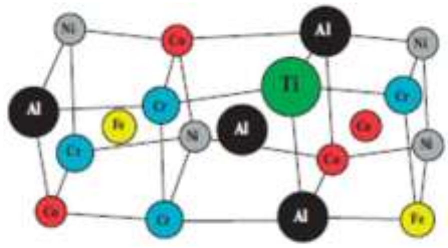

FIG.1 Schematic diagram of a BCC HEA as a solid solution

The hardness one of the most convenient ways to describe the mechanical properties of metallic properties (3). Vickers hardness testing can be done quickly and efficiently, without the need for a large volume of sample materials. For some thin-film HEAs, the yield stress of thin films cannot be measured directly, but micro hardness tests can easily be done with high precision. HEAs exhibit hardness values varying widely from 140 to 900 HV, depending on the alloy systems and related processing methods (2-4) (3) (5).

Table.1 Ideal configurational entropies in terms of R for equi-atomic alloys with constituent elements up to 13 elements.

n	ΔS_{conf}
1	0
2	0.69
3	1.1
4	1.39
5	1.61
6	1.79
7	1.95
8	2.08
9	2.2
10	2.3
11	2.4
12	2.49
13	2.57

Consider an equi – atomic alloy in its liquid state or regular solid solution state. Its configurational entropy per mole is calculated as

$$\Delta S_{conf} = -k \ln w = -R\left({}^{1}\!/_{n} \ln {}^{1}\!/_{n} + {}^{1}\!/_{n} \ln {}^{1}\!/_{n} + \dots {}^{1}\!/_{n} \ln {}^{1}\!/_{n}\right) = -R \ln {}^{1}\!/_{n} = R \ln n$$

Although the total mixing entropy has four contributions: configurational, vibrational, magnetic dipole, magnetic dipole and electronic randomness, configurational entropy is dominant over the other three contributions.

2. Exhaust valve

By opening and closing of the exhaust values in engine, the discharge and exhaust can be maintained regular intervals within the cylinder. Unfornatelly, fact that very high pressure and temperature of loads, the conventional valves do frequently fails before its life cycle. The valves are used in internal combustion to permit the exhaust gases to escape into the manifold. Because of the expansion of gases with extreme temperature and pressure. Apart kind high thermal stresses, these valves area unit exposed to cyclic mechanical stresses during opening and closing, inflicting the issues and them to fail untimely. It is evident of that a standard cause of valve fracture is fatigue. The current materials is nimonic alloy 80A which is nickel based. That portion of the stem immediately below the top is subject also to the warmth of the burning gases that, once the exhaust opens rush by it at a velocity of up to 91.4m/s; and to the corrosive action of unconsumed, hot oxygen and intermediate product of combustion (5).

2.1 Modeling of the exhaust valve

Basic terminology of exhaust valve,

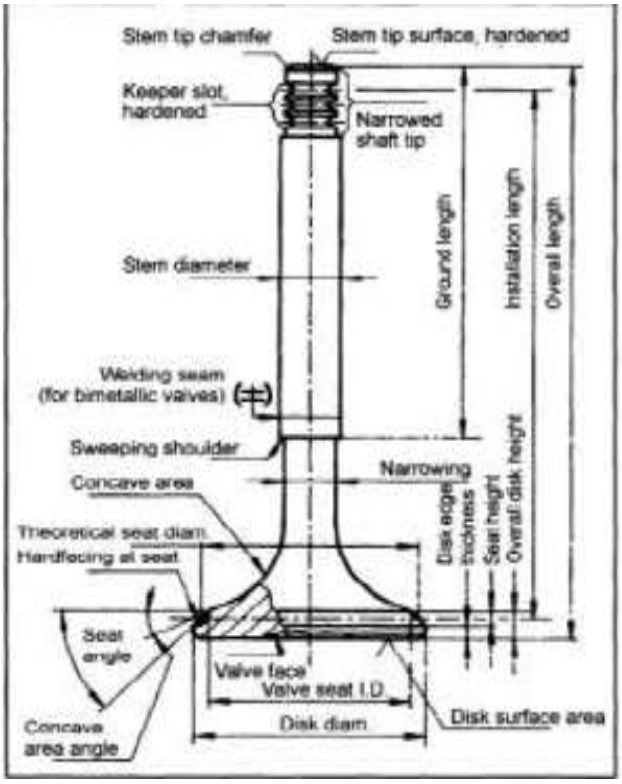

Fig.2 Basic terminology of exhaust valve

2.1.2 The design of exhaust valve:

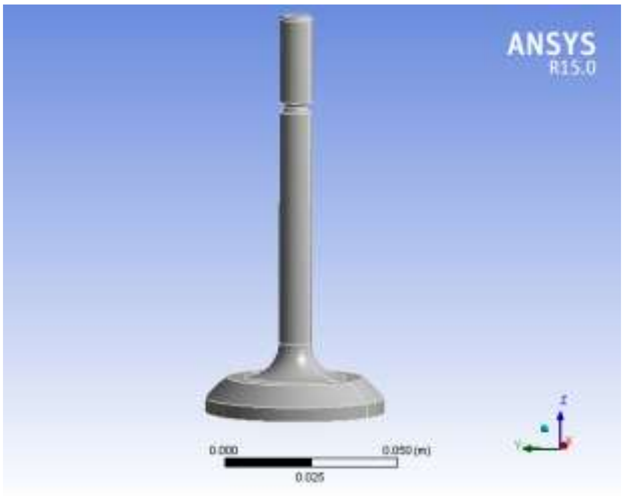

Fig.3 Design of exhaust valve

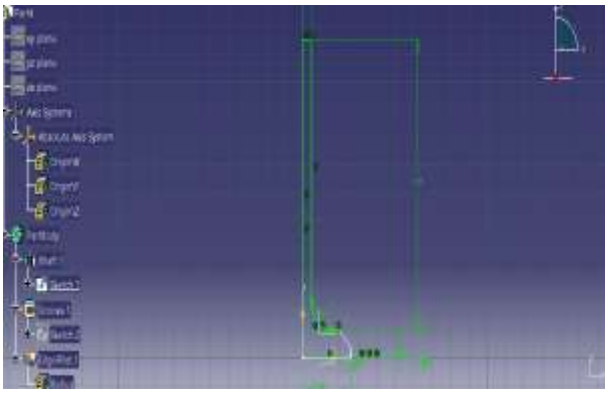

Fig.4 The dimensions of exhaust valve and seat angle, above figure shows poppet engine valve engine where all dimensions are in mm.

2.1.3 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 Exhaust engine valve
Diameter of valve port (Dp) = 27 mm
Width of valve (W) = 2mm
Valve angle (θ) = 45^0
Diameter of valve head (Dv) = 51.74 mm
Thickness of valve disk (t) = 2 mm
Margin (M) = 1.6 mm
Diameter of valve stem (Ds) = 10 mm
Maximum valve lift (hmax) = 10 mm

Kinematic motion of exhaust engine valve is governed by valve actuating mechanism generally push rod mechanism. This mechanism is driven by motion of a crank – shaft of engine and as a result of which exhaust engine valve continuously open and closes the ports which control the flow of gas through ports. 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 engine valve is continuously under tension and compression alternatively which lead to fatigue failure.

2.1.4 Valve design calculations:

Exhaust valve engine considerations:

Size of valve ports

$$V_g \times a = A_p \times C_{P_{ave}}$$

Where V_g = velocity of gas
a= area of port
A_p= area of piston
$C_{P_{ave}}$ = average piston velocity

$V_g \approx 2300$ to 3300 m/min for stationary / marine engine.

$V_g \approx$ 3300 to 5000 m/min for automobile engines

$$a = \frac{\pi d^2{}_{port}}{4}$$

$$A_p = \frac{\pi D^2}{4}$$

$$C_{P_{ave}} = 2L\ nm/min$$

For velocity of gas, to calculate port area and port diameter

$$V_g = \frac{14.7 V_g ¥_{ch} \times 180}{520P\ (180 + \alpha + P)}$$

where , V_g = velocity of gas

$(180 + \alpha + P)$ = duration of valve opening

T = temperature in Rankine

$¥_{ch}$= Charging efficiency

P = pressure of gas.

Port diameter = d_1=d_{port}

$$= {}^{D}\sqrt{\frac{(piston\ speed)\, mean}{velocity\ of\ gas\ through\ valve}}$$

Valve lift

$$h = \frac{0.25 d_1}{cos\alpha} = \frac{d_1}{4cos\alpha}$$

Thickness of valve disc

$$t = K_1\ d_1 \sqrt{\frac{P}{S}}$$

K_1 and S values are taken as per the materials peroperties.

P= maximum gas pressure

$d_1 = d_{port}$= port diameter or

$t = 0.5d_1\sqrt{\frac{P_{max}}{\sigma}}$ where σ is allowable stress

$$d_2 = d_1 + 2\ (t \times \sin(90 - \alpha_v))$$

$$d_3 = 0.5\ (d_2 - d_1)$$

$$=0.5\ d_1\left[\sqrt{\frac{S_b}{S_b - P_{max}}} - 1\right]$$

Where, S_b = safe bearing pressure

b = $0.05d_1$ to $0.07d_1$ an empirical formula (or)

b = $\frac{t}{tan\alpha}$ = $0.1\ d_1$ + 4mm

$d_0 = \frac{d_1}{18} + \frac{3}{16}$ inch

Where, d_0 = diameter of valve stem

α = valve face angle = 30^0 / 40^0

$$\text{Bearing pressure} = \frac{Load}{BearingArea}$$

$$= \frac{Load}{\frac{(d_2 - d_1)}{2} \times \pi \times d_1}$$

3.0 RESULTS AND DISCUSSIONS

In this project is found that the predominant cause of failure of valves of internal combustion engine is fatigue. The valves are subjected to high temperature, cyclic loading. Erosion – corrosion and high pressure inside the cylinder, thus making it critically important to know about under these conditions. In many cases study of fatigue failure mechanism, because the fatigue under actual loading conditions is different from simple mechanical fatigue failure. Thus thermal analysis carried out by high entropy alloys properties given shown in based on the structural and thermal results comparing with high entropy is better than the nimonic alloy 80a by considering the all properties of both the materials.

3.2 Static Structural Analysis

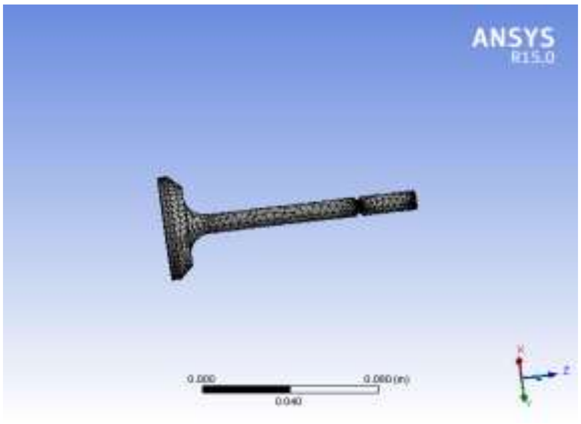

Fig.5 Meshing of exhaust valve

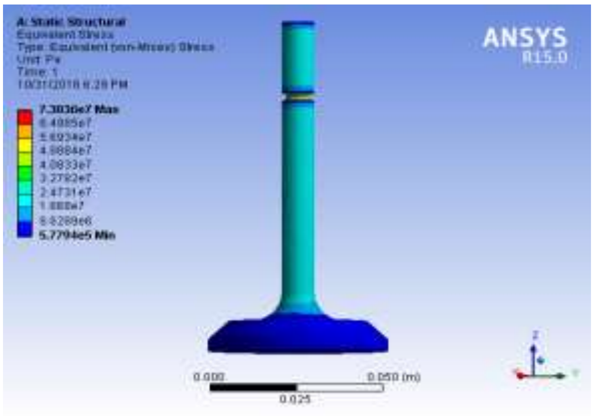

Fig.6 Equivalent stress analysis

3.3 Fatigue Analysis

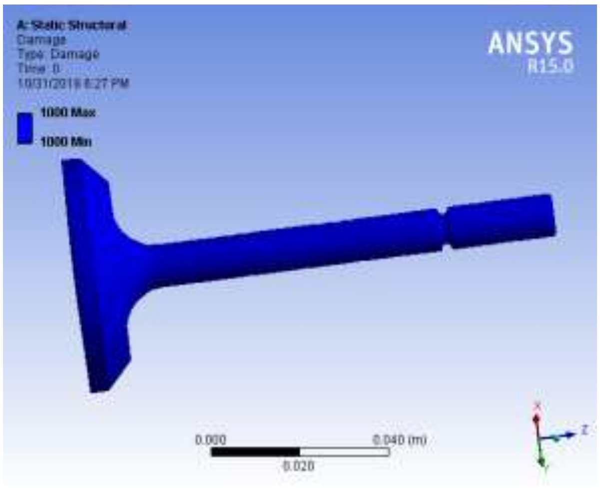

Fig.7 Damage of exhaust valve

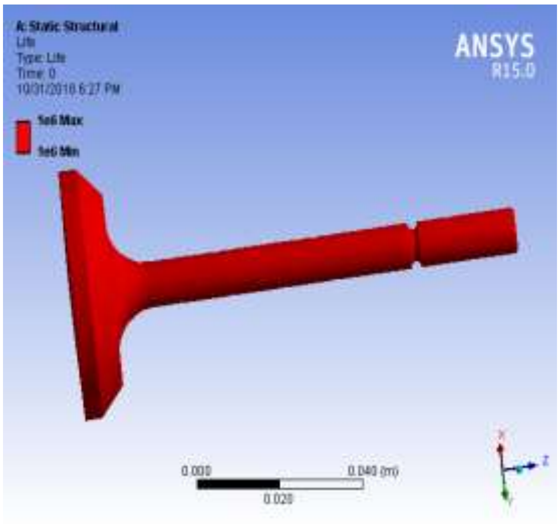

Fig.8 life of exhaust valve

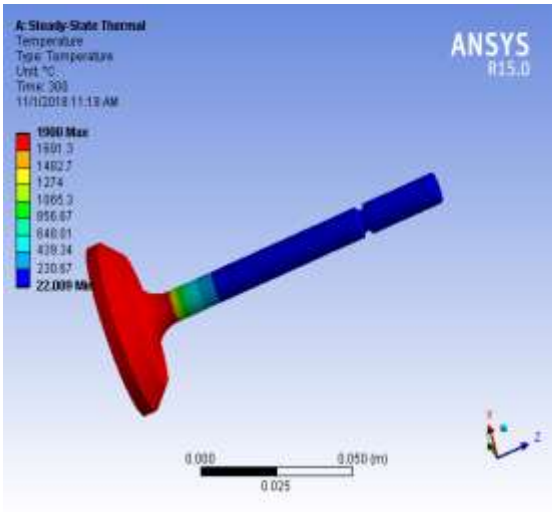

Fig.9 Deformation of exhaust valve

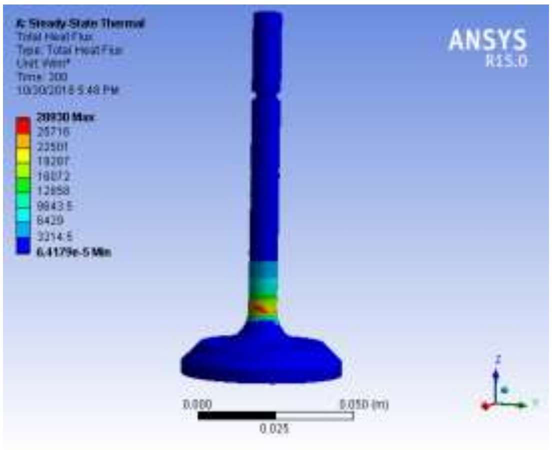

fig.10 Total heat flux in X – direction

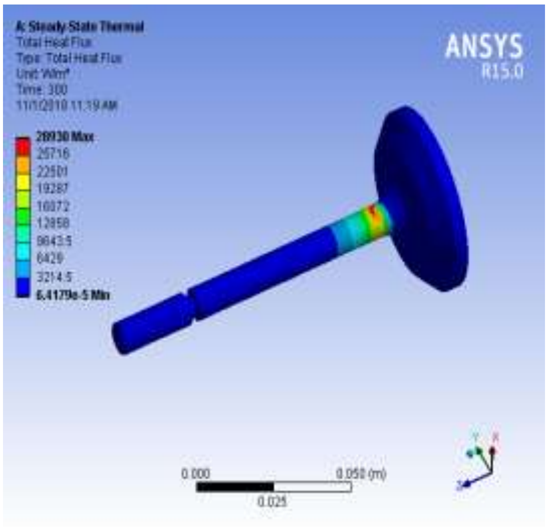

Fig.12 Total heat flux

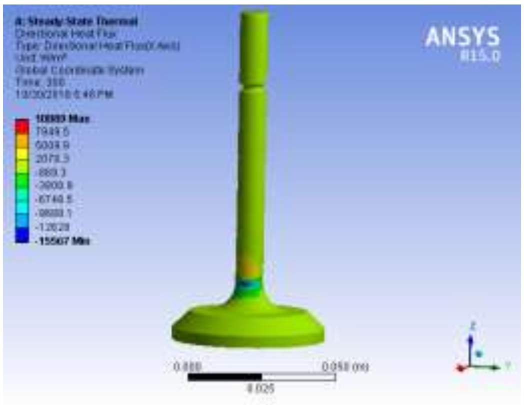

Fig.13 Directional heat flux

4. CONCLUSIONS

In this project it is planned to design automobile engine valve, using HEA's i.e high entropy alloys compared with the traditional valves made out of nimonic alloys, by comparing the both alloys consider high entropy alloy is efficient by compared by the nimonic 80A. Undertaking the all consideration the high entropy alloy the useful of maintaining eco-friendly environment because the taken materials are less destroys lift time and good corrosion resistance. It is bear with the very high temperature.

In the convection alloy only one element is priniciple one element and adding the minor elements in a small quatity. But in High entropy alloys are equi – atomic and non- equi atomic is mixing in the High entropy alloy to form multicomponent alloys.

High entropy alloys have the excellent mechanical, chemical, electrical and thermal properties. Thus using these properties in aerospace, food, structural and energy industrial [22]. The main thing of this material is cost of material is high but compare to other material the high entropy alloys properties are excellent.

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