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Experimental Investigation of Tensile Property of Aluminum Alloy (A383) by Hot Tensile Test for Piston Application

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ABSTRACT

Hot Tensile Test (HTT) is the method of testing the material properties at elevated temperature. In IC Engine the piston is subjected to high temperature in cylinder. So it is necessary to study the effect of high temperature on strength of piston material. Hot tensile test is carried out by using UTM with furnace & extensometer. The objective of this work is to study the mechanical behavior of aluminum alloy (A383) at elevated temperature (150^{0}C, 250^{0}C, 350 ^{0}C) & at different strain rates (0.05 per min & 0.1 per min.).

The expected result indicates that, (1) The stress decreases with the increase of temperature. (2)The stress decreases with the decrease of strain rate. (3) The elongation to fracture increases with the increase of temperature from 150 °C to 350 °C. (4) Ultimate load required for fracture of material decreases with increase of temperature. (5) For selected strain rate range (0.05 per min & 0.1 per min.), as the strain rate increases, there will be increases of the temperature corresponding to the maximum elongation to fracture. (6)For the same temperature range, as the strain rate increase from (0.05 per min & 0.1 per min.), the ultimate tensile strength of material also increase. This work compares existing piston material (A4032) with a new material (A383) for hot tensile test.

Keywords— **Elevated Temperature, Hot Tensile Test (HTT), Piston, Strain Rate, Tensile Strength.**

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I. INTRODUCTION

a Generally the prediction of behaviour of material at high temperature is very difficult. During design of components which are subjected to or working at high temperature must consider the testing at elevated temperature. Hot tensile testing (HTT) is the method of tensile testing of material at elevated temperature. Due to excellent mechanical properties, good corrosion resistance, breaking tenacity under elevated temperature, the superalloys are widely used in high temperature part of aviation and aerospace engines. Generally, the forging with large sizeand complex shape, such as turbine disks and engine shafts, are manufacture by multi-pass hot working process. The micro-structure of superalloys are very sensitive to the hot deformation parameters. Therefore, investigating the flow behaviour, microstructural evolution and fracture characteristics are very important to estimate the effect of deformation parameters on the formability under complex conditions [1].

Material flow behavior during hot formation process is often complex. The work hardening (WH), dynamic recovery (DRV) and dynamic recrystallization (DRX) often occur in the metals and alloys with low stacking fault energy during the hot deformation. For the multi-pass hot forming process, the static recrystallization and metadynamic recrystallization also occur. Especially, the effects of DRX behavior on the flow stress and microstructures are significant for the metals and alloys. Therefore, understandings of the relationship between the thermo-mechanical parameters and DRX behavior of metals and alloys is of great importance for designers of metal forming processes (hot rolling, forging and extrusion). It is well known that the dynamic recrystallization (DRX) can refine the grain during the hot deformation. As an important softening and grain refinement mechanism, the DRX has a great significance for the control of microstructures and the improvement of mechanical properties. The acceleration of DRX with strain rate is attributed to the increasing rate of dislocation accumulation during high strain rates and high temperature. It is popularly understood that accessional substructurescan be generated in the initial grains when the strainrate is high, which will produce more nuclei per unit volume ofthe grains. This mechanism can make the grain fine when the strain rate is high. When the strain rate is decreased, the dynamicrecovery rate increases and the dynamic recovery proceedsadequately or the recrystallization occurs during the hot deformation [2].

II. PISTON MATERIAL

We can use the hot tensile testing (HTT) method to study the mechanical properties of materials used for piston. Initially the cast iron material is used for piston but due to low thermal conductivity and heavy weight now a day's steel and aluminium alloy are used for piston.

The most common material used for automotive pistons is aluminium due to its light weight, low cost, and acceptable strength. Although other elements are present in smaller amounts, the alloying element of concern is silicon in aluminium pistons. Using an alloy having a composition beyond the eutectic point i.e., more than 12% Si, offers lower coefficient of thermal expansion, and therefore, engine designers are permitted to specify much tighter tolerances. Due to pistons intricate structure, the use of hyper-eutectic composition of silicon is justified, since it increases the fluidity or the viscosity of the molten aluminium used. However, adding silicon to pistons makes them more brittle and thus making the piston more susceptible to cracking if the engine experiences pre-ignition or detonation [3].

III. OBJECTIVE

The objectives of present work:

1. To study the effect high temperature on tensile strength of aluminium alloy by HTT (A383),
2. To study effect of strain rate on tensile strength of aluminium alloy by HTT (A383),
3. Comparison of tensile property of existing material of piston (A4032) with new piston material (A383).

IV. LITERATURE SURVEY

Deepak Sharma et al. focused on determining the tensile properties from stress strain curve by tensile testing of aluminium (specimen) at different range of high temperature(37ºC, 90ºC, 130ºC, 170ºC, 210ºC, 250ºC, 290ºC, 325ºC). True Stress and strain is calculated using the engineering equation. Using the values of true stress and true strain, the true stress strain curve was plotted. The polynomial equation is obtained from each specimen curve. The graph is plotted between temperature and ultimate tensile strength (UTS) which indicates that the ultimate tensile strength decreases with the increase in temperature. Also to predict the behaviour of aluminium at different high temperature (room temperature to 325ºC).

Mi Zhou et al,this paper focused onhot tensile deformation behaviours and constitutive model of an Al–Zn–Mg–Cu alloy. The hot tensile deformation behaviours of an Al–Zn–Mg–Cu alloy are studied by uniaxial tensile tests under the deformation temperature of 340ºC –460 ^{0}C and strain rate of 0.01–0.001 s^{-1}. The effects of deformation temperature and strain rate on the hot tensile deformation behaviours and fracture characteristics are discussed in detail.The tensile true stress–true strain curves of the studied Al– Zn–Mg–Cu alloy under all the deformation conditions can be divided into four distinct stages, i.e., elastic stage, uniform deformation stage, diffusion necking stage and localized necking stage. The flow stress decreases with the increase of deformation temperature or the decrease of strain rate. The localized necking causes the final fracture of specimens under all the deformation conditions. Microvoids coalescence is the main fracture mechanism under relatively low deformation temperatures. With the increase of deformation temperature, the intergranular fracture occurs.

Josip Brnic, Marko Canadija, Goran Turkalj, and Domagoj Lanc [2012] This paper presented work on structural steel ASTM A709—behaviour at uniaxial tests conducted at lowered and elevated temperatures **(250ºC, 400ºC, 500ºC),** short-time creep response, and fracture toughness calculation. It can be seen that ultimate strength level after temperature of 250°C decreases, while 0.2% offset yield strength level decreases during all of temperature regime increasing. According to the data, the material becomes quite useless in conditions including service temperature higher than 500°C. This conclusion is also in accordance with creep behaviour. Namely, ASTM A709 steel may be used or treated as quite creep resistant, when the stress level is under 50% of 0.2% offset yield strength 117 MPa at the temperature of 400°C, and under 25% of 0.2% offset yield strength 44 MPa at the temperature of 500°C. When temperature is higher than 500°C, this steel is not sufficiently creep resistant. With reference to lowered temperature, it is seen that both ultimate and 0.2% offset yield strengths slightly increase with the decrease of temperature.

Yuan-Chun Huang et al. the hot tensile deformation behaviors of 42CrMo steel are studied by uniaxial tensile tests with the temperature range of 850–1100 °C and strain rate range of 0.1–0.0001 s^{-1}. It is found that the flow stress firstly increases to a peak value and then decreases, showing a dynamic flow softening. This is mainly attributed to the dynamic recrystallization and material damage during the hot tensile deformation. The deformation temperature corresponding to the maximum elongation to fracture increases with the increase of strain rate within the studied strain rate range. Under the strain rate range of 0.1–0.001s^{-1}, the localized necking causes the final fracture of specimens. While when the strain rate is 0.0001s^{-1}, the gage segment of specimens maintains the uniform macroscopic deformation. The damage degree induced by cavities becomes more and more serious with the increase of the deformation temperature.

Y.C. Lin et al. The hot tensile deformation behaviors and fracture characteristics of a typical Ni-based superalloy are studied by uniaxial tensile tests under the deformation temperature range of 920–1040 °C and strain rate range of 0.01–0.001 s^{-1}. Effects of deformation parameters on the flow behavior, microstructural evolution and fracture characteristics are discussed in detail. The results show that the flow behaviors are significantly affected by the deformation temperature, strain and strain rate. Under relatively low deformation temperatures (920, 950 and 980 °C), the flow curves are composed of three distinct stages, i.e., work hardening, steady stress and flow softening stages. The flow curves show the typical DRX characteristics under relatively high deformation temperatures (1010 and 1040 °C). With the increase of deformation temperature or the decrease of strain rate, the fraction of recrystallized grains increases. The synthetical effects of localized necking and microvoid coalescence cause the fracture of the studied superalloy under all the deformation conditions.

L.J. Huang et al. investigated Hot tensile tests were performed on Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy with an equiaxed microstructurein the temperature range of 900–980 °C with a constant strain rate of 0.001 s^{-1}.It is seen that the elongation of all the specimens exceeds 200% in the temperature range of 920–980 °C, and a typical superplastic deformation shapes with uniform deformation. Increasing temperature leads to higher elongation and the highest elongation (400%) is observed at 960 °C. However, visible local necking and low elongation (only 100%) are observed at 900 °C, indicating the low deformation ability of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy with an equiaxed microstructure below 900 °C.

SUN Sheng-di et al. investigated that when the strain rate is kept constant, the flow stress decreases gradually with increasing the hot deformation temperature. When the strain rate is $7.7\times10-2$ s^{-1}, the flow stress almost decreases linearly with the increase of the deformation temperature. When the temperature is below 800 °C, the flow stress decreases sharply with increasing the deformation temperature, whereas the flow stress decreases slowly with increasing the deformation temperature when the temperature is above 800 °C. This is due to the fact that the impact of work-hardening vanishes when the strain rate is below a critical value, resulting in the fact that the flow stress is determined by the activated energy. When the deformation temperature is higher than 850 °C, the flow stress increases with increasing strain until reaching the peak value, followed by a constant until fracture. At 900°C, the flow stress peak is below 25 MPa. The deformation is mainly controlled by dynamic re-crystallization at high deformation temperature.

The true stress−true strain curves under different strain rates at 750 °C. It is found that the tensile strength increases with increasing the strain rate. In addition, when the strain rate is higher than7.7×10^{-3} s−1, the specimens fracture before the strain reaches 0.25, which indicates that the TC4 alloy has poor deformability at high strain rate. The higher the strain rate is, the poor the hot tensile deformability is. This indicates that the strain rate plays an important role in the hot deformation process of TC4 alloy.

Horng-Yu Wu et al. presented the work on hot deformation behaviour of Inconel 600 Ni-based superalloy. Hot tensile test was carried out in the temperature range 850-1150 °C& at strain rate 0.001-1s^{-1}. During hot deformation, flow stress is function of dislocation density after yielding. In the stress-strain relation, the flow stress increase & reaches to peak valve, indicating that a dynamic equilibrium between hardening & softening occurs during hot deformation. The stresses increase with increasing strain rate & decreasing temperature.

V.MATERIAL PREPARATION

The material used in this present work is commercially aluminium alloy (A383). The Ingot of (A383) material was prepared in Sudal Industry, Ambad, Nasik.

The chemical compositions (wt %) of alloy are shown in table 1. This test was perform as per ASME E-21:2009 using gauge diameter in the range 9.8 mm to 10 mm, gauge length 50 mm and overall length of specimen is 120mm. for this test, temperature of this specimen is maintain at 150^0C, 250^0C, and 350 ^{0}C throughout the test to obtain correct result. Six circular dumbbell shape specimen were prepared & tested on SHIMADZU AUTOGRAPG AG-IS, Computerized Universal Testing Machine at ELCA LAB, PUNE. For this test, strain rate on specimen is maintained at 0.05 per min, 0.1 per min throughout the test to obtain correct result. This strain rates are responsible for displacement in specimen when tension applied, and this displacement measured by extensometer placed in furnace.

Chemical composition of the Aluminium-alloy (A383):

Table No. I

Si	Fe	Cu	Mg	Mn	Ni	Zn	Sn	Other	Al
12	1.3	3	0.1	0.5	0.3	3	0.15	0.05	Bal

A] Hot tensile test set-up:

Fig. 5.1 shows that the hot tensile set-up made by SHIMADZU AUTOGRAPH, showing the furnace consists of aluminium specimen. This machine consists of temperature control knob on panel to set the temperature between (0-900^0C). Temperature inside the furnace is continuously monitored by thermo-couple placed inside the furnace.

Fig.1 Hot Tensile Testing SHIMADZU AUTOGRAPH
(ELCA LAB, Pune)

According to the dimension mentioned above, the tensile force in specimen is twice the applied load through the hydraulic jack. All tests were conducted under steady state condition. After the specimen was fixed as shown in fig. 1, the kiln temperature was raised to the required temperature and then held constant for half an hour to allow the test specimen to reach the same temperature. During the load test, there was no temperature measurement of specimen to minimize the damages to the test specimen. However, temperatures inside the kiln and on specimen surface were continuously measured by thermo-couples. In addition, a temperature monitoring study was conducted before the strength tests. During the strength test, the target temperature was maintained and the test sample was loaded to failure.

VI.RESULT & DISCUSSION

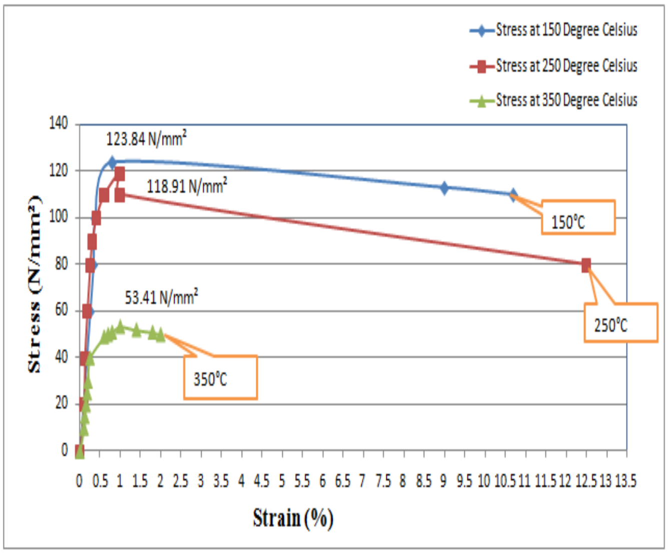

Fig. 2: Stress-Strain graph at different temperature with 0.05/min strain rate

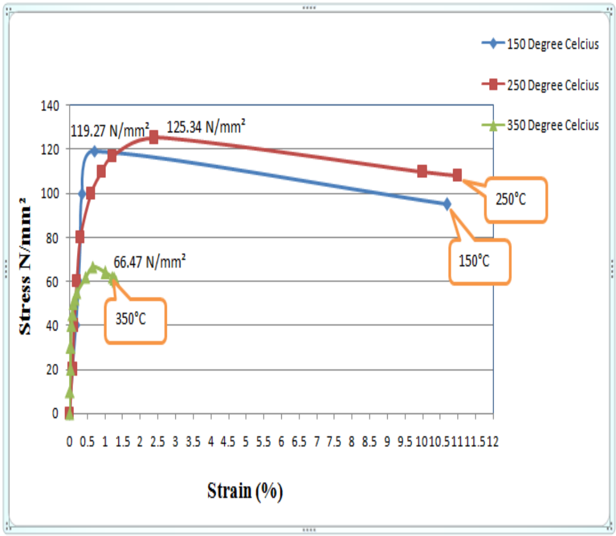

Fig.3: Stress-Strain graph at different temperature with 0.1/min strain rate

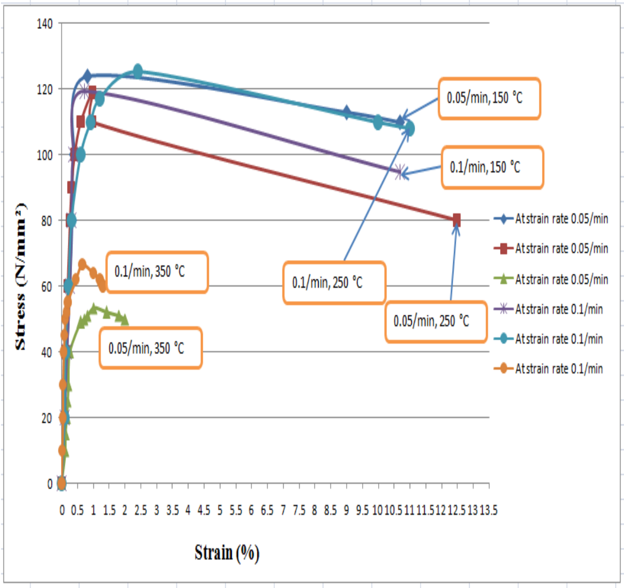

Fig.4: Combine Stress-Strain graph at 150 °C, 250°C, 350°C temperature & with 0.05 per min, 0.1 per min strain rate

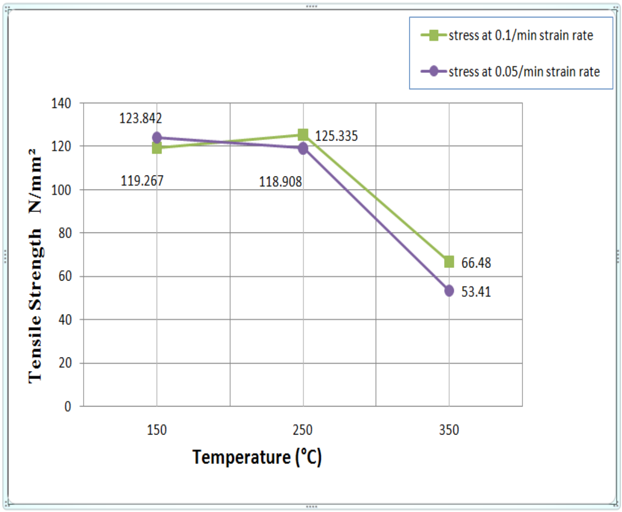

Fig.: 5: Tensile Strength Vs Temperature

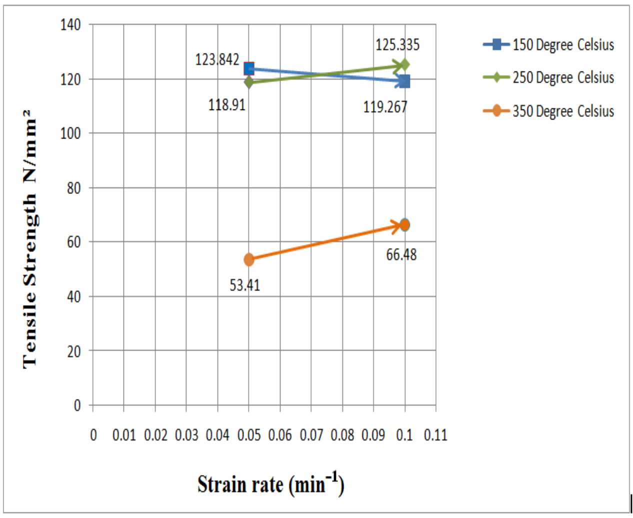

Fig.: 6: Tensile Strength Vs Strain rate

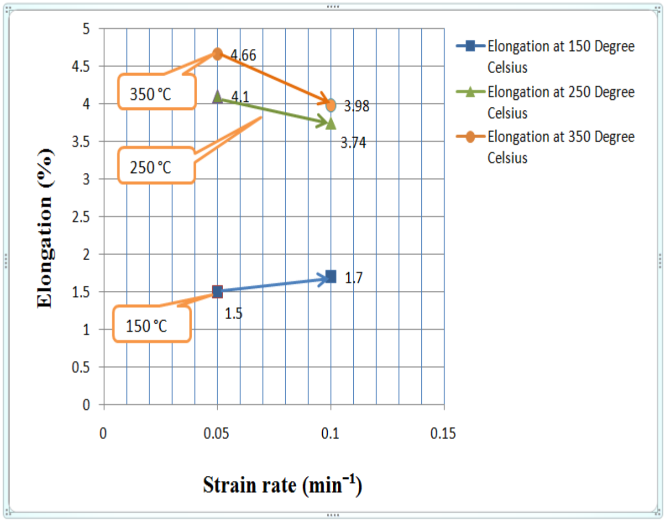

Fig.: 7 Elongation Vs Strain rate

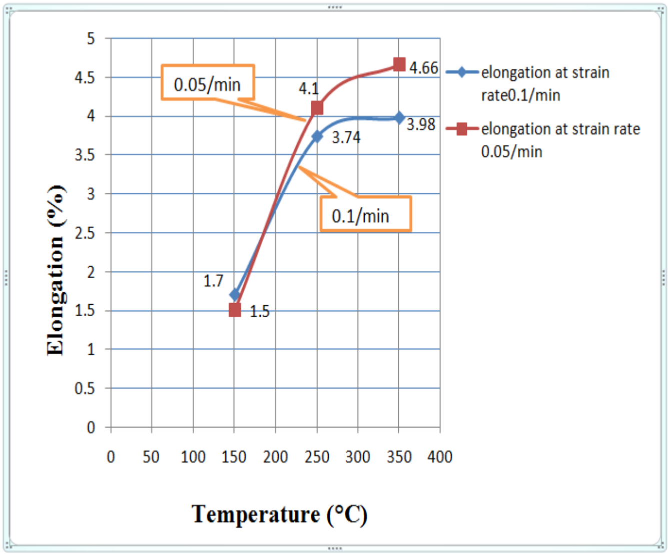

Fig. 8: Elongation Vs Temperature

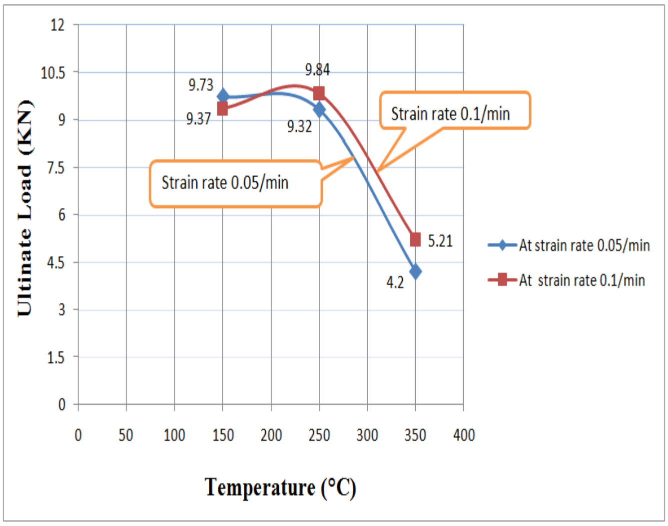

Fig.9: Ultimate load Vs Temperature

Fig. 10: Fracture specimen under temperature 150 °C, 250°C, 350°C with strain rate 0.05 per min, 0.1 per min

Tensile test was carried out by maintaining the constant strain rate of 0.05 per min with different temperature of **150 ^{0}C, 250 ^{0}C, and 350 ^{0}C** for three different specimens. The entire three specimens were failed within gauge length (WGL).

From fig 2, at strain rate 0.05/min, maximum stress obtained up to 123.84 N/mm^2, at 150 ^{0}C. For 250 ^{0}C maximum stress is 118.91 N/mm^2 and at 350 ^{0}C the maximum stress is 53.41 N/mm^2 from above experimental result we can conclude that, as the temperature increases from 150 ^{0}C to 350 ^{0}C, the tensile strength of aluminium material decreases from 123.84 N/mm^2 to 53.41 N/mm^2. The tensile strength was drastically decreases when temperature increases due to decrease of dislocation generation rate and the dislocation density.

From fig 3, at strain rate 0.1/min, maximum stress obtains up to 119.27 N/mm^2 at 150 °C. For 250 °C the maximum stress obtained was 125.34 N/mm^2 and at 350 °C maximum stress obtained was 66.47 N/mm^2. From above experimental observation, it was seen that, at 0.1/min strain rate, the tensile strength of aluminium material initially increases from 150 °C to 250 °C and then as temperature further increases from 250 °C to 350 °C the tensile strength of aluminium alloy decreases.

From fig 4, for temperature 150°C as strain rate increases from 0.05/min to 0.1/min, the tensile strength is decreases. But as the temperature increases to 250 °C, 350 °C, and the tensile strength will also increases with increases of strain rate from 0.05/min to 0.1/min.

From fig 5, at constant strain rate of 0.05 per min, the tensile strength of aluminium material is decreases continuously from 123.842 $N/mm^2$to 53.37 N/mm^2. But for higher strain rate of 0.1 per min the tensile strength initially increases from 119.27N/mm^2 to 125.34 N/mm^2 as temperature increases from 150 °C to 250 °C. Tensile strength decreases to 66.48 N/mm^2 for further increase in temperature from 250 °C to 350 °C.

From fig 6, (a) At temperature of 150 ^{0}C, as strain rate increases from 0.05/min to 0.1/min, the tensile strength decreases from 123.84 N/mm^2 to 119.27 N/mm^2.

(b) But at temperature 250 ^{0}C, as strain rate increases from 0.05/min to 0.1/min, tensile strength of aluminum material increases from 118.91 N/mm^2 to 125.34n/mm^2.

(c) At 350 ^{0}C also, as the strain rate increases from 0.05/min to 0.1/min tensile strength of material is increases from 53.45N/mm^2 to 66.48 N/mm^2. So it is concluded that as strain rate increases, tensile strength will also increases.

From fig 7, At 150 ^{0}C, as strain rate increases from 0.05/min to 0.1/min percentage of elongation is increases from 1.5 KN to 1.7 KN. But at 250 ^{0}C and 350 ^{0}C, as strain rate increases from 0.05/min to 0.1/min, the percentage elongation was decreases from 4.1 KN to 3.74 KN and 4.60 KN to 3.98 KN respectively. So from above result it is concluded that, increase in strain rate causes decrease in elongation as temperature is increases to higher range.

From fig 8, For lower temperature range from 150 ^{0}C to 250 ^{0}C, increment in percentage elongation is more (i.e. from 1.7 KN to 4.1 KN) than at higher temperature range 250 ^{0}C 350 ^{0}C.As strain rate increases from 0.05/min to 0.1/min percentage elongation is decreases from 4.1 to 3.74 KN and 4.66 to 3.98 KN at 250 ^{0}C & 350 ^{0}C respectively.

Fig 9 Shows, at strain rate 0.05/min, as temperature increases, the ultimate load required to break the specimen is continuously decreases as the temperature increases from 150^{0}C to 350^{0}C. But in case of strain rate 0.1/min (i.e. at higher strain rate), initially ultimate load increases from 9.37KN to 9.84KN, as temperature increases from 150^{0}C to 250^{0}C, but again increase in temperature from 250^{0}C to 350^{0}C, the ultimate load again decreases from 9.84KN to 5.21KN.

From above result, we can conclude that as temperature increases the load required to break specimen (or to generate crack) is reduces.

Fig. 10 shows The Fracture Specimen tested under different deformation temperature & strain rates.

The deformation capacity of specimens is good. For lower strain rate 0.05/ min the elongation to fracture is more than at 0.1/min strain rate for higher temperature 350°C.But for lower temperature 150°C, 250°C, the elongation to fracture is more for 0.1/min than strain rate of 0.05/min

VII.TECHNOLOGY

Aluminium-Silicon (AI-Si) alloys are most versatile materials, comprising 85% to 90% of the total aluminium cast parts produced for the automotive industry. Depending on the Si concentration in weight percent (wt. %),

The AI-Si alloy systems fall into three major categories:

1. Hypoeutectic (<10% Si),
2. Eutectic (10-13% Si) and
3. Hypereutectic (14-25% Si).

At high silicon levels the alloy exhibits excellent dimensional stability, low thermal expansion, high surface hardness and wear resistant properties. The silicon gives the alloy a high elastic modulus and low thermal coefficient of expansion. The addition of silicon is essential in order to improve the fluidity of the molten aluminium to enhance the castability of the AI-Si alloy. At high silicon levels the alloy exhibits excellent surface hardness and wear resistance properties. [4]

A] LIMITATIONS OF HYPOEUTECTIC & HYPEREUTECTIC

1] The "2618" performance piston alloy has less than 2% silicon, and could be described as hypo (under) eutectic. This alloy is capable of experiencing the most detonation and abuse while suffering the least amount of damage. Pistons made of this alloy are also typically made thicker and heavier because of their most common applications in commercial diesel engines. Both because of the higher than normal temperatures that these pistons experience in their usual application, and the low-silicon content causing the extra heat-expansion, these pistons have their cylinders bored to very much cold-play. This leads to a condition known as "piston slap" which is when the piston rocks in the cylinder and it causes an audible tapping noise that continues until the engine has warmed to operational temperatures. These engines (even more so than normal engines) should not be revved when cold, or excessive scuffing can occur [4].

2] Adding silicon to pistons makes them more brittle and thus making the piston more susceptible to cracking if the engine experiences pre-ignition or detonation (A390) [3].

B] CURRENT MATERIAL USED FOR PISTON

Table No. II

Hypoeutectic (0.25<% Si)	**Eutectic (10-13%Si)**	**Hypereutectic (16-18% Si).**
A2618, A2024-T6	A4032	A390
A 201	A413	

Piston is also subjected to fatigue stresses during working, so material must have good fatigue strength. From above comparison we can observe that proposed material had more fatigue strength & melting point. We can replace A4032 alloy by A383 material for better working of piston.

In present work, tensile property of material A383 is tested by hot tensile test (HTT) at 350 ^{0}C, 0.05/min is compared with FEA result of material A4032 at 357 ^{0}Cstudied by S. Bhattacharya et al.

It is also observe that, for nearly same temperature range tensile property of A383 at 350 ^{0}C is 53.37 MPa while for material A4032at 357 ^{0}C is 21.4 MPa. So we conclude that tensile property of A383 at 350 ^{0}C is much higher than A4032 at 357 ^{0}C.

Hence, new material A383 is best replacement for A4032 under same temperature range.

C] Comparisons of eutectic piston materials [11, 12]

Table No. III

Parameters	A4032	A383
Fatigue strength (MPa)	110	145
Melting point (°C)	657	660

D] Comparisons of existing piston material (A4032) with new material (A383)[3]

Table No. IV

Piston material	Temperature	Tensile strength
A4032	357°C	21.4 MPa
A383	350°C	53.37 MPa

VIII.CONCLUSION

1] At lower strain rate 0.05 per min, the tensile strength of aluminium material is decreases continuously from 123.842 $N/mm^2$to 53.37 N/mm^2. But for higher strain rate of 0.1 per min, the tensile strength initially increases from 119.27N/mm^2 to 125.34 N/mm^2 as temperature increases from 150 ^{0}C to 250 ^{0}C. Tensile strength decreases to 66.48 N/mm^2 for further increase in temperature from 250 ^{0}C to 350 ^{0}C.

2] For lower temperature 150 ^{0}C as strain rate increases, tensile strength was decrease. But for higher temperature 250 ^{0}C, 350 ^{0}C as strain rate increases, tensile strength will also increases.

3] At 150 ^{0}C, as strain rate increases from 0.05/min to 0.1/min percentage of elongation is increases from 1.5 KN to 1.7 KN. But at 250 ^{0}C and 350 ^{0}C, as strain rate increases from 0.05/min to 0.1/min, the percentage elongation was decreases from 4.1 KN to 3.74 KN and 4.60 KN to 3.98 KN respectively. So from above result it is concluded that, increase in strain rate causes decrease in elongation as temperature is increases to higher range.

4] For lower temperature range from 150 ^{0}C to 250 ^{0}C, increment in percentage elongation is more (i.e. from 1.7 KN to 4.1 KN) than at higher temperature range 250 ^{0}C 350 ^{0}C.As strain rate increases from 0.05/min to 0.1/min percentage elongation is decreases from 4.1 to 3.74 KN and 4.66 to 3.98 KN at 250 ^{0}C & 350 ^{0}C respectively.

5] To overcome from the limitation of hypo-eutectic piston material such as the low-silicon content causing the extra heat-expansion, these pistons have their cylinders bored to very much cold-play, they are much thicker and heavier which increase weight.

6] To overcome from the limitation of hyper-eutectic piston material such high silicon content makes pistons more brittle and which causes cracking in a piston if the engine experiences pre-ignition or detonation.

7] From conclusions 5,6 the eutectic aluminium (A383) will used for piston in future for better performance. At higher temperature & at higher strain rate, we can use this proposed material because it has low elongation.

8] In future we can use A383 material for piston which had high fatigue strength &tensile strength, melting point than current used A4032 material.

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