Evaluation of Tensile Properties Using Uni-Axial Testing and Correlation with Microstructure of AA2014 alloy

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Abstract. AA2014 is most widely used metal among the aluminium alloy series due to its exceptional corrosion resistance, low density rate, and it can maintain high strength and toughness at various temperatures. So, these materials have their application in the aerospace, military and the automotive sector. The present work focuses on evaluating the mechanical properties such as ultimate Tensile strength (UTS), Yield strength (YS), and percentage of elongation using Uniaxial Tensile test. The three controllable factors used in the present study are temperature ranging from 200 to 300°C with 50°C increment, orientation 0,45,90 degree relative to the rolling direction and strain rate 0.001,0.01 and 0.1mm/sec. A total of 27 experiments were planned and conducted based on the design of experiments. Experimental results show that with increase in strain rate increasing of material properties furthermore with increase in temperature decrease of material properties and increase in the percentage of elongation was observed. In addition to that ANOVA analysis was carried out and noticed that strain rate is most effecting parameter for UTS and temperature is most effecting parameter for YS and percentage elongation. The fracture specimens from uniaxial test are investigated for type of fracture through microstructural studies

1. Introduction

Aluminium alloys are the second most widely used alloys in the infrastructure in this current era followed by the ferrous alloys due to the extraordinary properties of these alloys, like

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exceptional corrosion resistance, low density rate, high strength, these materials have their application in the aerospace and the automotive industries[1] .2xxx alloys (Al-Cu) are more frequently used in these applications due to the result of strength compared to other aluminium alloys[2]. AA2014 is the frequently used alloy in the aerospace sector because of its high hardness and ease of machining. AA2014 is the second most popular in aluminium series after AA2024. Usually, AA2014 is extruded and forged[3]. AA2014 is Precipitation-hardened aluminium alloy based on Al-Cu-Mg. This type of mixture helps in achieving an excellent combination of mechanical properties such as high tensile strength, excellent strain hardening, and ductility[4] . Chromium is one of the other elements responsible for the noncorrosive characteristics towards oxidation. This substance will resist the metal by forming a thin coating of chromium oxide on the surface of the AA2014 sheet to resist the effects of corrosion, it also consists silicon and manganese in small quantity which serve as deoxidizers[5] .By the process of precipitation hardening, these alloys will obtain their strength. These alloys are artificially aged, which causes coherent precipitate strengthening to form in the aluminium matrix, giving off increased strength as a result of coherency stresses around each precipitate. AA2014 is Al-Cu-Mg-Si based composition[6] . By the process of precipitation of strengthen phases of the Al_2Cu and Al_2Cu mg phases it develops higher resistance to damage tolerance and strong resistance to fatigue crack propagation compared to the other alloys[7] . These alloys can be heat treatable, controlled by adding the suitable alloying elements with respective heat treatment. Aluminium alloys are precipitation hardened as a result of theta phase precipitation from hyper saturated solid solution. And there are various methods available regarding the differential solarizing and the differential age treatment. Many studies were focused on just the precipitation behaviour of the alloying elements and also the fatigue, creep behaviour[8-11] .So, using these alloys at different conditions there is a need to evaluate the properties of the material by using different control factors.Pandoura et.al,[12] addresses on static as well as dynamic fracture and toughness on AA2014 and concluded that, Temperature increases with increase in toughness when compared with static fracture toughness decreases. The significance of dynamic rupture initiating toughness is higher at room temperature and yield strength, plastic zone size was optimum at room temperature. Narender et.al,[13] compared aluminum alloys with the AA2014 at Peak aged and solution treating conditions and reported that AA2014 has a perfect balance of isotropy and for some further process into structural parts for automotive and aerospace applications. They also reported that the work hardening exponent is as high as compared to other tensile values obtained from the experiments. John et.al,[14] studied a friction stir process on AA2014 at various parameters and concluded that the microstructure, grain size and mean hardness of the treated region has more influence on rotational speed. Sivaraman et.al,[15] in his investigation study, described about the wear behavior of AA2014 and AA2024 using friction stir welding process and concluded that for aerospace application low erosion coefficient, temperature, noise levels are recommended. Dwivedi et.al,[16] concluded that when addition of reinforcements such as SiC, Al_2O_3, TiC, B_4C, SiO_2, and iron powder in the micro or nano-size can change the microstructural features that leads to good physical and mechanical qualities in the alloys particularly for aerospace applications. Pandouria et.al,[17] in his study concluded that as the temperature increases up to 200 °C the flow stress decreased gradually and beyond that it is reduces surpassingly. Moreover, when the temperature rises from 25 °C to 250 °C, the true fracture strain increased from 14.8 to 51.5%. Navya et.al,[18] through their investigation observed that due to the enhanced dislocation density and grain size effectiveness, it has been discovered that the tensile strength of Ultra Fine grade Aluminum Alloy has greatly risen when compared to its bulk Aluminum Alloy. Madhusudan et.al,[19] compared precipitation hardening and artificial aging treatment on AA2014 alloy. Precipitation hardening and artificial aging has been accomplished at 542˚C for 3.5 hours along with water quenching and 183˚C for 2 to12 hours respectively. The findings demonstrate that AA2014 aluminum alloy reaches its maximal hardness (129.2 BHN) after 8 hours of ageing.

Therefore, in the present study an attempt has been made to evaluate the mechanical properties such as UTS, YS, % of elongation. In addition to that ANOVA analysis was performed to investigate which parameter contributes more in Uniaxial tensile test. Further microstructural characterization was performed using scanning electron microscope to know the type of fracture. of the AA2014 by conducting a total of 27 uniaxial tensile test with respect to full factorial design by three controlling factors Temperature, Orientation, Strain rate.

2. Experimental details

2.1. Specimen preparation

AA2014 sheets were procured from the local vendor, to confirm the material chemical analysis was performed on the received material and showed in Table 1. A full factorial design of experiments (27) were planned with the process parameters shown in Table 2. The parameters and levels are choosed based on the machine conditions and literature review. A total of 27 samples were prepared in accordance with the standards of ASTM-E8M with the three orientations as shown in Figure 1 using wire EDM process.

Table 1. Chemical composition of AA2014 sheet

Sample	Cr	Si	Mn	Zn	Ti	Fe	Mg	Cu	Al
AA2014	0.006	0.897	0.756	0.045	0.019	0.133	0.599	4.519	Rest

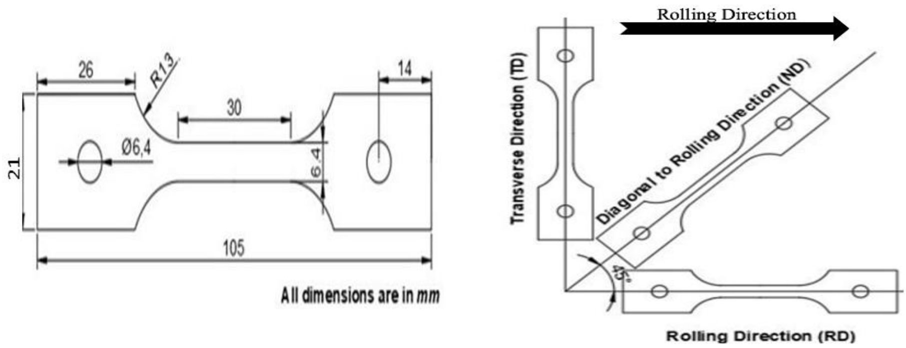

Fig. 1. Illustrative Tensile test Specimen (ASTM E8M) with three orientations (0.45,90)

2.2 Experimental Setup

Uniaxial Tensile test Experiments were carried out on Universal Testing Machine (make: BISS, Model:AC-06-0040) with heating frequency ranging from room temperature to 900C as shown in figure 3. Before loading the samples in the machine, samples were cleaned with 100 and 1200 grade emery paper to remove the rease/ oil/foreign particles on the surface of the samples. After loading the tensile specimens in the machine, furnace temperature was increased up to desired temperature and holding about 30 minutes to homogenize the tensile specimens. After every experiment furnace is cooled to room temperature. The same procedure was repeated for 27experimnnets and the results were reported on Table 3.

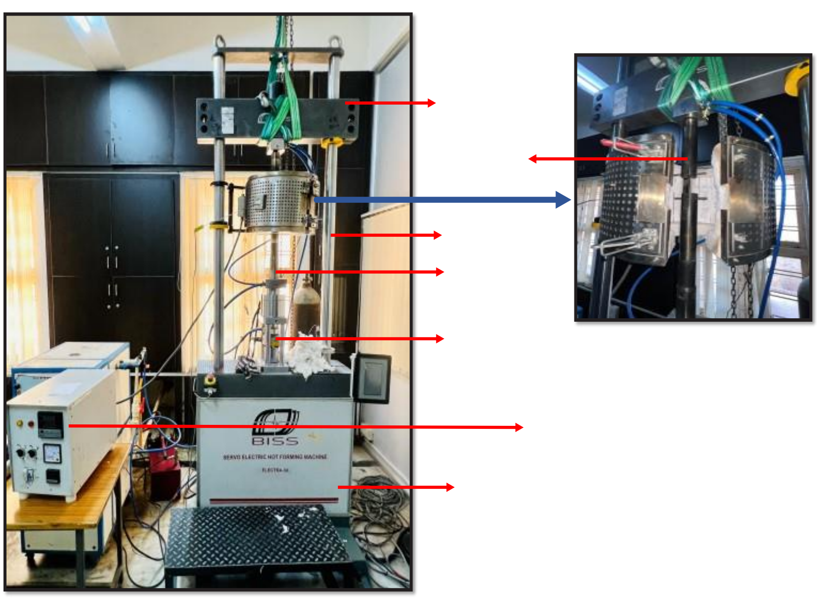

Fig. 2. Representation of UTM & Experimental setup

A sample load vs displacement graph was obtained from the inbuilt BISS software shown in Figure 3, corresponding value of UTS and YS from the graph are generated through BISS software. % Of elongation has been calculated by using the formula (ΔL/L) x 100.

Table 2. Design Matrix

Std	**Run**	**Temperature (°C)**	**Orientation**	**Strain Rate (mm/sec)**	**YS (Mpa)**	**UTS (Mpa)**	**% Of elongation**
1	18	200	0	0.001	413	540	24
2	12	250	0	0.001	345	515	30.5
3	14	300	0	0.001	360	518	31
4	13	200	45	0.001	420	585	26
5	09	250	45	0.001	369	526	31
6	10	300	45	0.001	380	525	31.3
7	22	200	90	0.001	425	610	27
8	03	250	90	0.001	428	530	31.5
9	07	300	90	0.001	390	528	32
10	17	200	0	0.01	433	622	27.5
11	11	250	0	0.01	388	545	31.5
12	20	300	0	0.01	410	533	32
13	06	200	45	0.01	440	651	28
14	26	250	45	0.01	409	561	32
15	16	300	45	0.01	432	540	32.5
16	25	200	90	0.01	452	664	29
17	04	250	90	0.01	466	565	32.5
18	08	300	90	0.01	468	545	33
19	01	200	0	0.1	488	676	29
20	24	250	0	0.1	388	568	32.5
21	02	300	0	0.1	456	545	33
22	21	200	45	0.1	470	683	30
23	15	250	45	0.1	409	580	32.8
24	23	300	45	0.1	470	556	33.5
25	05	200	90	0.1	484	695	32
26	27	250	90	0.1	466	588	33
27	19	300	90	0.1	480	567	34

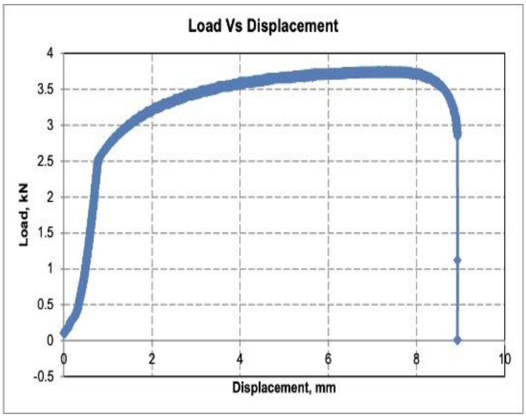

Fig. 3. Load vs Displacement graph

3. Results and Discussion

In the present work Properties of the material has been evaluated at varying Temperature, Strain rates and Orientation are discussed. The experimental results shows that the flow behavior of AA2014 has great sensitivity to both the strain rate and temperature. Mainly, the UTS, YS of AA2014 is decreased while increasing the temperatures, and the percentage of elongation started to increase simultaneously while increasing the temperature and strain rate. Flow stresses of the material started to decrease gradually while increasing the temperatures. Due to the high temperatures the dislocations of the atoms become weaker as small stress is enough to break the specimen, also the flow stress and work hardening behavior of the AA2014 starts to increase as a result of it. Meanwhile as the experimental strain rate is increased the strength of the material also started to increased rapidly and as well as the percentage of elongation also started to increase. From the fig. 4-6, it is notified that as the strain rate increases, the UTS increases and considerably increase in the YS and Percentage of elongation also observed. Generally, at low temperatures the thermal agitation is low because of the internal energy of the atom is considerably low and it vibrates less. So, when these thermal agitations are low the atoms will become denser and it requires large stress to pull the dislocations from their equilibrium positions, allowing them to keep their higher strengths. Several ductile materials that have high melting points can be reinforced in this way. At, higher strain rates the strength and percentage of elongation of AA2014 is increased due to the time it takes for materials to flow plastically or release generated tensions. In terms, when the strain rate is increasing gradually the dislocations will pile up and resist the further deformation of the material which causes the more amount of strength inducing in it. The UTS, YS and percentage of elongation was observed high in the 90-degree angle with respect to rolling directions compared to the other orientations. From the graphs it was observes that maximum value of UTS, YS is 694Mpa, 484Mpa which occurred at temperature of 200°C in 90-degree orientation and the minimum value is 515Mpa, 345Mpa which occurs at a temperature of 300°C. Furthermore, the maximum elongation occurs at a temperature of 300 degree is 34% and minimum elongation occurs at a temperature 200°C is 24%.

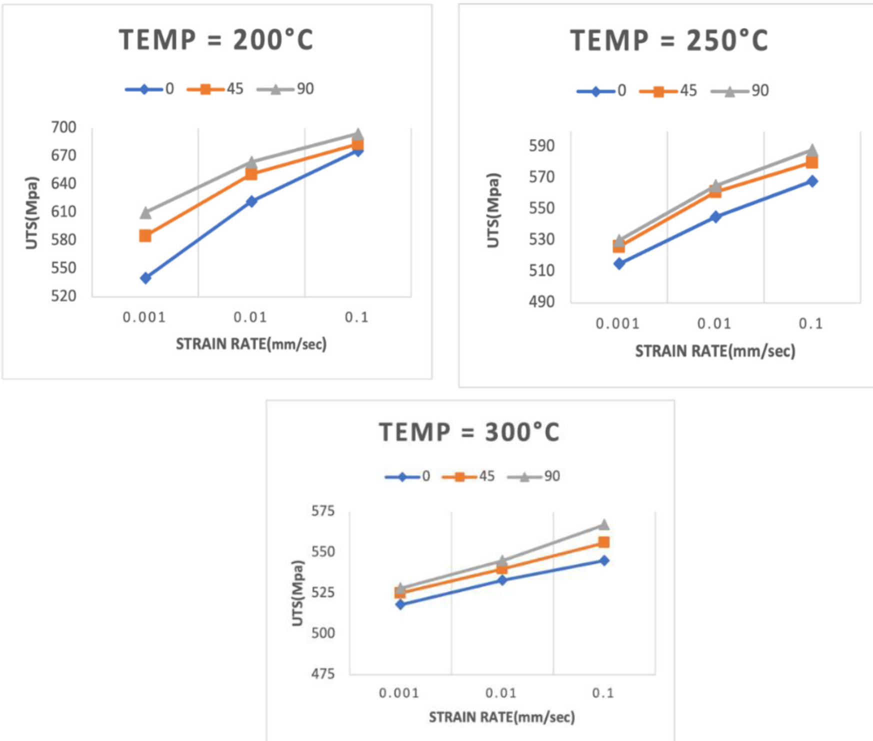

Fig. 4. Variation of UTS with various strain rates.

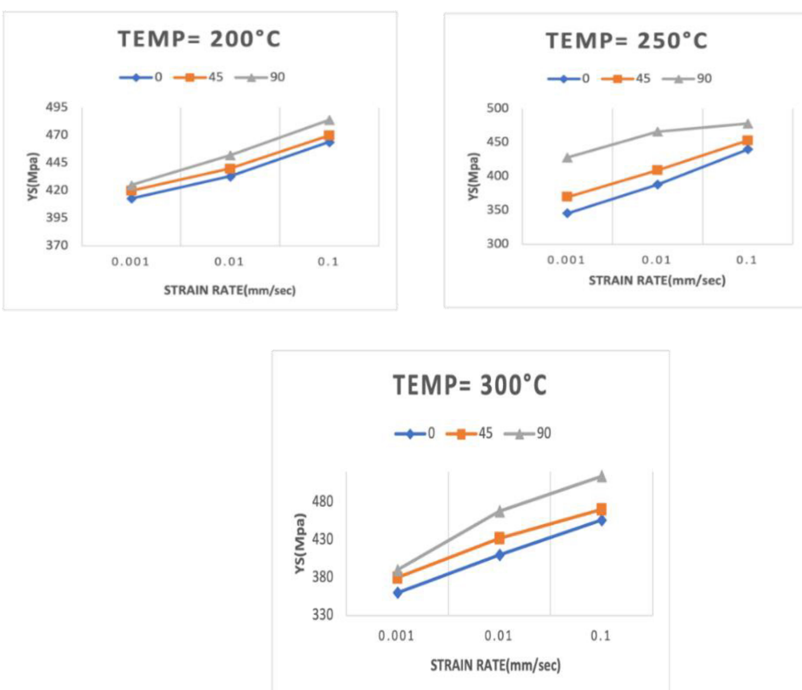

Fig. 5. Variation of YS with various strain rates.

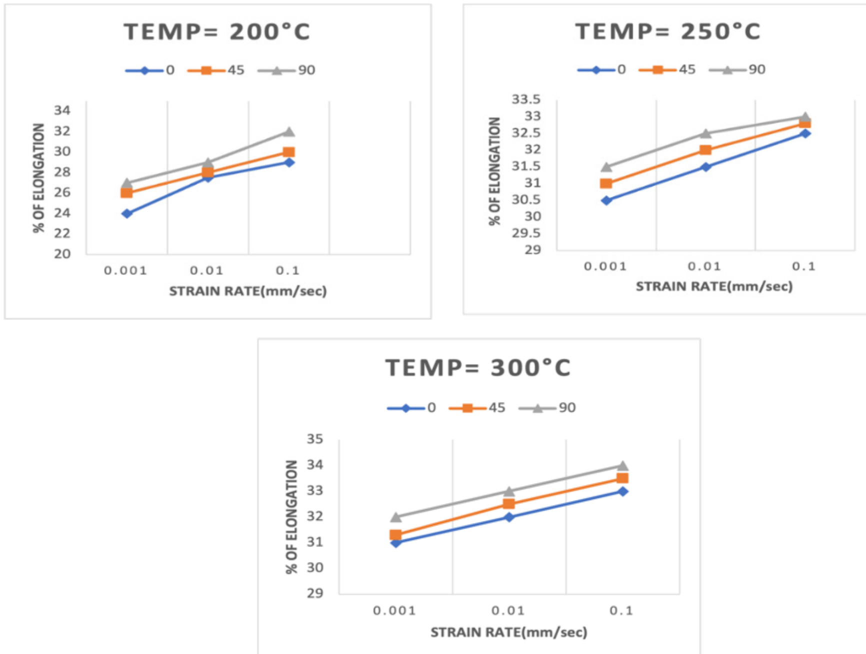

Fig.6. Variation of % Of elongation with various strain rates

4. ANOVA Anlaysis

Sir Ronald fisher was firstly introduced the ANOVA (Analysis of variance)**[20] .** Using Minitab statistical software, this analysis was carried out at 95% confidence level. The main aim of ANOVA is to determine which parameters have a substantial impact on performance attributes **[21]**. From table 3 the most contributing parameter for UTS was observed to be strain rate with 28.35%. From Table 4 and Table 5 i.e., for YS and % of elongation it was observed that temperature is the most contributing factor with 25.73% and 33.2%.

Table 3. Analysis of variance UTS

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%Contribution
Regression	5	69634	13926.8	39.31	0.000	
strain rate	1	10048	10048.3	28.36	0.000	28.35
Temperature	1	8889	8889.0	25.09	0.000	25.08
Strain rate*Strain rate	1	6254	6254.4	17.65	0.000	17.65
Temperature*Temperature	1	7257	7257.0	20.49	0.000	20.48
Strain rate*Temperature	1	2637	2636.8	7.44	0.013	7.44
Error	21	7439	354.3			1.00

Table 4. Analysis of variance YS

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%Contribution
Regression	5	25956.7	5191.3	5.82	0.002	
strain rate	1	3629.3	3629.3	4.07	0.057	17.45
temperature	1	5351.0	5351.0	6.00	0.023	25.73
strain rate*strain rate	1	5032.7	5032.7	5.64	0.027	24.20
temperature*temperature	1	4988.2	4988.2	5.59	0.028	23.99
strain rate*temperature	1	902.5	902.5	1.01	0.326	4.34
Error	21	18730.0	891.9			4.29

Table 5. Analysis of variance % Of elongation

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%Contribution
Regression	5	143.848	28.7697	33.50	0.000	
strain rate	1	14.650	14.6499	17.06	0.000	21.84
temperature	1	22.269	22.2689	25.93	0.000	33.20
strain rate*strain rate	1	8.655	8.6548	10.08	0.005	12.90
temperature*temperature	1	16.778	16.7780	19.54	0.000	25.01
strain rate*temperature	1	3.868	3.8677	4.50	0.046	5.77
Error	21	18.034	0.8588			1.28

5 Fractography Studies

In the present study fractography studies were carried out using SEM (Model: ZESSE018) for the specimens were maximum values of UTS, YS, and % of elongation was observed. Samples were prepared of size 5mm/5mm with the help of wire EDM process. It was observed from Fig 7, Fig 8, Fig 9 the presence of voids, dimples, on the fractured surface which will confirm that material is ductile in nature of failure. From the Fig 7, Fig 8, Fig 9 Microcracks, Micropores are observed in all the cases of SEM analysis. Black line shows the flow direction of elements pitching, Fine grain arrangement of elements after elongation leads to no cracks, coarse grain arrangement of elements leads to micro pitching micro pitching are observed.

Table 6. Elemental properties of AA2014 alloy composition **[22]**

Elements	element number in periodic table	content%	Crystal structure	Melting point(c) Kelvin Celsius	Thermal conductivity W/mK	thermal expansion um/(mk)	
Al	13	93.5	FCC	933.5	660.35	235	23.1
Cu	29	4.4	FCC	1357.8	1084.65	400	16.5
Si	14	0.98	Diamond cubic	1687	1084.65	150	2.6
Mg	12	0.5	HCP	923	649.85	160	24.8
Cr	24	0.1	BCC	2180	1906.85	94	4.9
Mn	25	0.6	BCC	1519	1245.85	7.8	21.7

It can be observed from Table 6 that mg is having low melting point and high thermal expansion next to the Mg, Al has also same properties. This indicates that metal with Mg and Al will have high effect towards metal failure as the temperature raise. In the present study experiments are performed at a Temperature of 200°C,250°C,300°C. Due to increase in the Temperature the atomic bond becomes more ductile, resulting in high strain rate and lower tensile strength. In addition to this, there will be internal heat produced due to the moment of elements and de-bonding of the atoms in elements and metals will takes place which may increase the heat beyond the experimental temperature due to which metal undergoes plastic deformation stage and give rise to failure

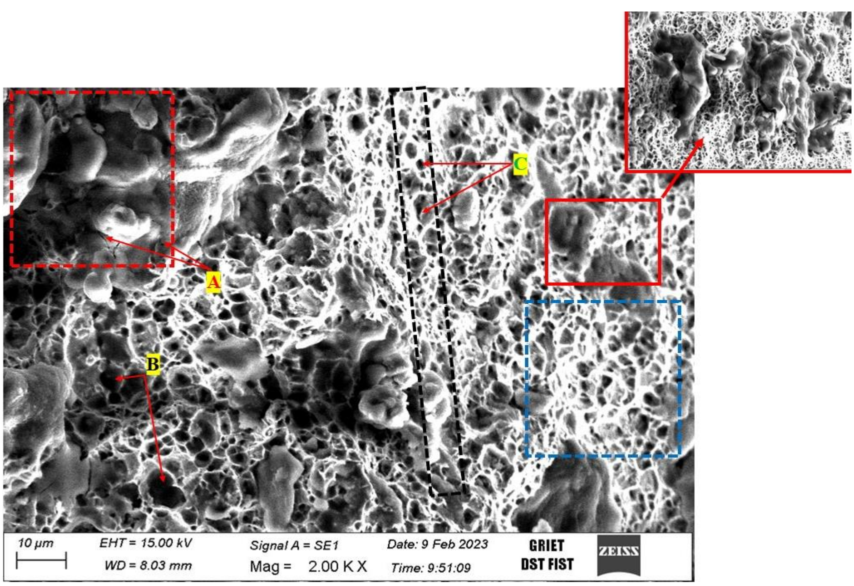

Fig.7. Micro-structure at Max YS of 488MPa at stain rate 0.1mm/sec, 0^0 orientation and 200^0C temperature.

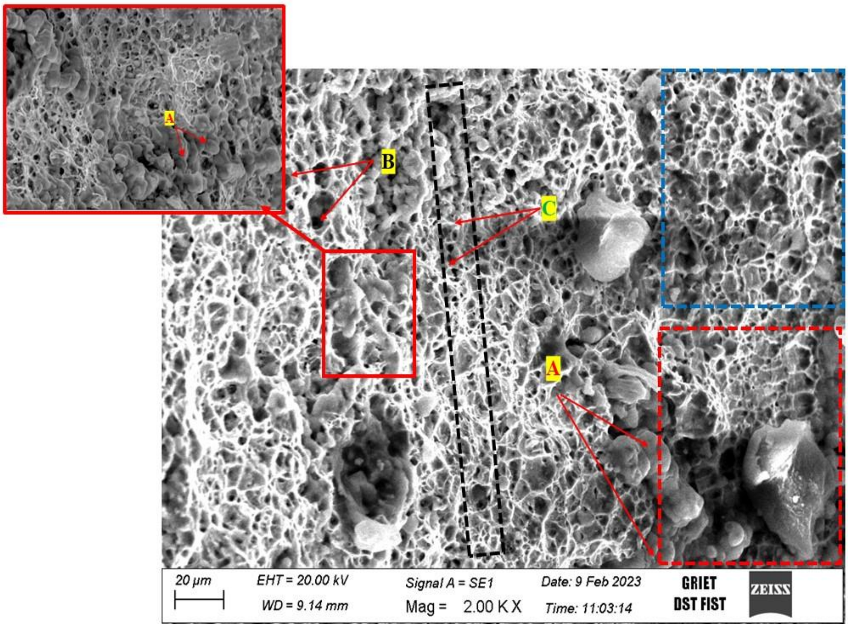

Fig. 8. Micro-structure at Max elongation of 34 at stain rate 0.1mm/sec, 90^0 orientation and 300^0C temperature.

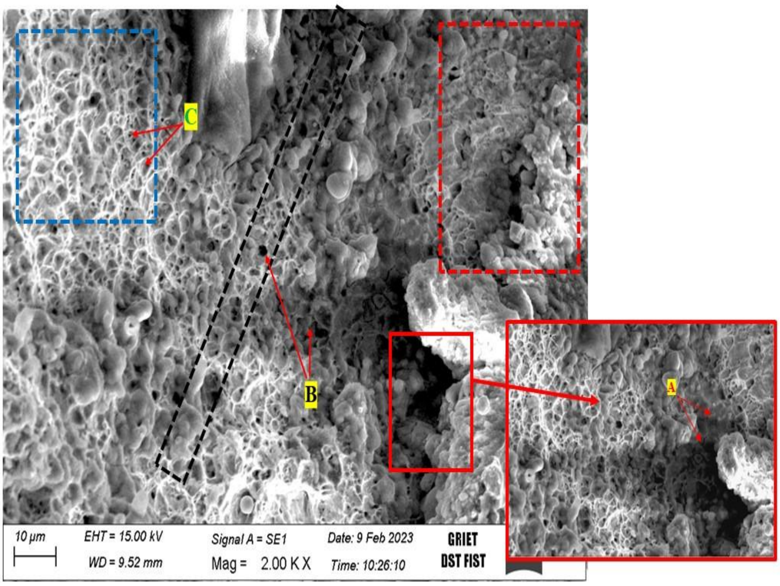

Fig. 9. Micro-structure at Max UTS of 695 MPa at stain rate 0.1mm/sec, 90^0 orientation and 200^0C temperature.

A. Micro cracks
B. Macro pores
C. Micro pores

6 Conclusions

An attempt was made to investigate the properties of UTS, YS, and % Of elongation of the AA2014 sheet by the influence of temperature, strain rate, and the orientation. The key findings from the study are:

- With increase in strain rate increasing of material properties was observed.
- With increase in temperature decrease of material properties and increase in the % of elongation was observed.
- Upon comparison of specimens of different orientations 90 degree-oriented sample observed to be having a high material property.
- Through ANOVA most contributing parameter for UTS, YS, % of elongation was strain rate with 28.35%, Temperature with 25.73% and 33.2.

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