Study of mechanical properties, microstructures and corrosion behavior of al 7075 t651 alloy with varying strain rate

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Abstract

Compression test of Al 7075 T651 was carried out at high strain rates ($1138 – 2534$ s^{-1}) using Split Hopkinson Pressure Bar and at slow strain rate ($10^{-4}s^{-1}$) in 100KN Universal Testing machine to understand the improvement in mechanical properties and associated changes in microstructures. Cylindrical specimens of 6 mm height and 6 mm diameter were compressed dynamically. The influence of strain rates on mechanical properties, microstructure evolution and corrosion behavior after immersion test in 3.5% NaCl solution was also investigated. Strain rate, withdrawal stress and yield stress were observed to increase with impact velocity in high strain rate tests, while in slow strain rate tests, n value was observed to increase with increasing total strain. Microstructural observations revealed that after high strain rate test, grains of Al matrix were elongated. It was observed that corrosion resistance decreased with increase in impact velocity.

1. Introduction

Al 7075 is a very important alloy for automobile and aeronautics industries [1]. Now a days this material is used quite extensively for automotive body and aircraft structures because it has higher strength and lower weight. Considerable amount of work has been carried out on this material under the high and low strain rates at various loads [2-4]. However, there has been very little work concerning the effects of loads and strain rate on aluminum 7075 and evolution of microstructures after deformation at high and slow strain rates.

In current research, Split Hopkinson Pressure Bar is used [5-7] for high strain rate and uniaxial compression for slow strain rate deformation. By using this technique, it is proved that significant changes occurred in mechanical response under increased load or strain rate.

The objective of this study is to compare the changes in mechanical behavior of aluminium 7075 alloy after deformed in high and slow strain rate at same condition. The stress - strain relation, withdrawal stress, strain-strain rate comparison, n value and microstructure evolution are discussed in terms of test conditions. For corrosion studies immersion test for 30 days in 3.5wt% NaCl solution has been done. The change in corrosion rate has been studied during this test of the deformed samples in high and slow strain rate.

2. Experimental Procedure

Material used is Al7075 T651which has the following composition:

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Table 1. Composition of Al7075 alloy in wt%

Composition	Wt%
Zn	6.886
Cu	1.561
Mg	1.605
Si	0.035
Fe	0.83
Cr	0.092
Ti	0.049
Mn	0.023
Li	0.041
Al	Balance

The material received T651 thermo mechanical treatment, consisting of a solution heat treatment for 30 min at 748 K (475°C), a water quenching and a final aging at 394 K (121°C) for 24 h. This material has yield stress (YS) of 502 MPa, ultimate tensile strength (UTS) of 572 MPa. The percentage of failure elongation of this material is up to 11% and young modulus is 72 GPa. Cylindrical specimen was used for the test. The materials were supplied as plates then it was cuts into cylindrical shape which has 6 mm diameter and 6 mm height approximately.

The purpose of SHPB test was to obtain high strain rate properties. The operation of SHPB was done in four conditions of load which are 4 kg/mm², 6 kg/mm², 8 kg/mm² and 10 kg/mm². Four experiments have been performed at each condition to satisfy the condition of repeatability.

2.1. High strain rate test

Specimens were loaded between the incident and transmission bars for the SHPB tests. The pressure was set at 4 kg/mm² then the striker bar launcher was pressurized with air compressor. The specimen was compressed by the impulse from the incident bar generated due to gas gun ignition. This collision created a compression pulse, or stress wave, that propagated through the bar toward the specimen. This wave was called incident wave which was recorded by the incident strain gages. Once the wave reached the specimen, it splited into two smaller waves. The transmitted wave traveled through the specimen and into the transmission bar where the energy was recorded by the transmission strain gauge. The second wave was reflected away from the specimen and traveled back down the incident bar. Both strain gages measured the strain duration and amplification in the bars. The reflected pulse recorded by the incident strain gauge was used to calculate strain. The portion of the compression pulse that continues through the specimen was recorded by transmission gauge and used to calculate stress. Data from the strain gauges was routed through amplifiers and an oscilloscope to where it was stored. Then collected the compressed sample and measured it dimension for future work. This procedure was also done in other conditions of pressure. At the end of the experiment we got all data of strain, strain rate, stress and stress strain curves

2.2. Slow strain rate test

Slow strain rate deformation was carried out in a 100 KN BISS universal testing machine. Specimens were subjected to compressive load during deformation. Specimen dimensions during this test were same as those during the high strain rate deformation test. Slow strain rate compression was carried out at a crosshead speed of 0.5mm/min leading to the strain rate of 10^{-4}/s. Specimens were strained under compressive load to different total strains (ε_T). The extent to which specimens have to be strained, that is the value of the total strain (ε_T), was decided on the basis of the total plastic strain (ε_P) sustained by the specimens at each load during high strain rate tests. During slow strain rate test, specimens were subjected to same values of plastic strain as given in high strain rate test for different loads. To know the amount of total strain to which the specimens had to be compressed for a given

plastic strain, a specimen was subjected to total strain of 40%. From the data of this particular test, total strain corresponding to required plastic strains was calculated. Other specimens were than subjected to same total strains to get the desired plastic strains. The specimens were subjected to 14%, 20%, 25% and 30% total strain to get the corresponding plastic strain of 13%, 19%, 24% and 29%, respectively.

2.3. Corrosion Studies
Samples were first polished for corrosion test. After polishing samples were ultrasonically cleaned in acetone to remove any kind of particles, because corrosion is a surface phenomenon therefore any kind of anomaly in the surface (scratches, pits, dirt etc) can play a negative role in corrosion resistance. For immersion test, the circumferential area of the samples was coated with Teflon tape to reduce the area effect from corrosion. The immersion test was carried out in 3.5% NaCl solution.

2.3.1. Immersion test. Immersion test is easier, simpler controlled test method than other test. Immersion tests measures the progress of corrosion damage of the samples in corrosion environment. Here the laboratory tests were carried out the ASTM standard G-103. Two samples of high strain rate test and one sample of slow strain rate were prepared for immersion test. These polished samples were dipped inside different conical flask containing 250 ml of 3.5 wt% NaCl solution (ph-7.5-8.5) for 30 days at room temperature (~ 30°C) and the flasks were sealed with aluminum foil. Teflon tape was used to hang the samples and to avoid any kind of contact corrosion. After completing the test the samples were cleaning with acetone in ultrasonic cleaning machine for 10 to 15 minutes. The cleaning was done preferentially to remove the oxide layer from the surface.

Figure 1. Al 7075 t651 sample in immersion test

After immersion test corrosion rates were estimated by weighing the cleaned specimen in a digital balance (Mettler Toledo XS-205 model).The corrosion rate in meter per year (m/y) was calculated from the weight loss data for the samples obtained after immersion test using this formula:
Corrosion rate = 534 W/ DAT
Where, W = weight loss in mg
D = density in g/cm3 = 2.81 g/cm^3 for aluminum 7075 alloy
A = area of specimen in cm^2
T = total time exposure time in hours

3. Result and Discussion

3.1. High strain rate deformation
3.1.1. Stress, strain & strain rate curve. In Fig. 3(a-d) stress, strain and strain rate curves are plotted for different impact velocities where the strains are 0.13, 0.18, 0.25 & 0.29 and strain rates are 1141

s^{-1}, 1749 s^{-1}, 2153 s^{-1} & 2552 s^{-1}. These figures shows that stress and strain rates are dependent with strain. With strain increasing stress is increased where the strain rate is decreased. But both stresses and strain rates are increased with impact velocity.
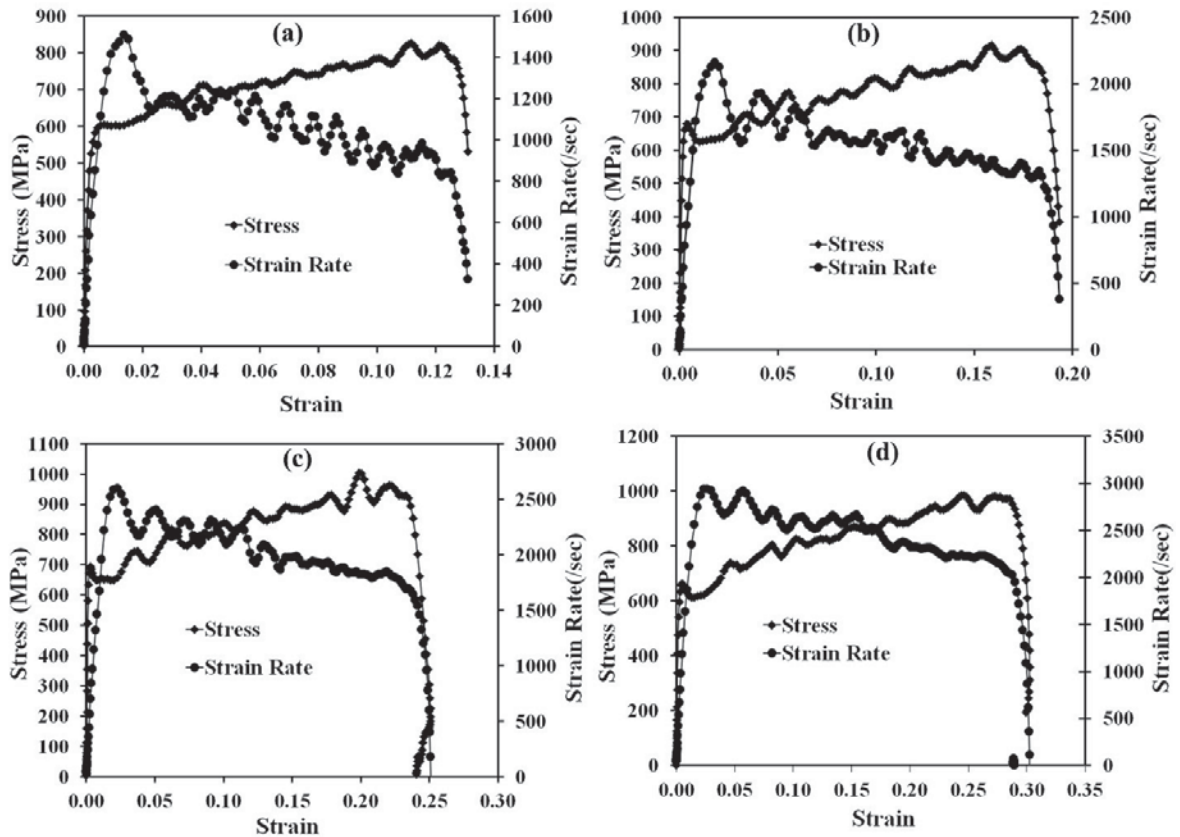

Figure 2(a-d). Stress, strain & strain rate curve at different loads.

3.1.2. Impact velocity vs average strain rate, Withdrawal stresses, Strain at withdrawal stress and yield stress curve. The average values of impact velocity, strain rate, withdrawal stress, strain at withdrawal stress and yield stress are calculated from the raw data which are given below.

Table 2: Average values of strain rate, withdrawal stress, Strain at withdrawal stress and yield stress

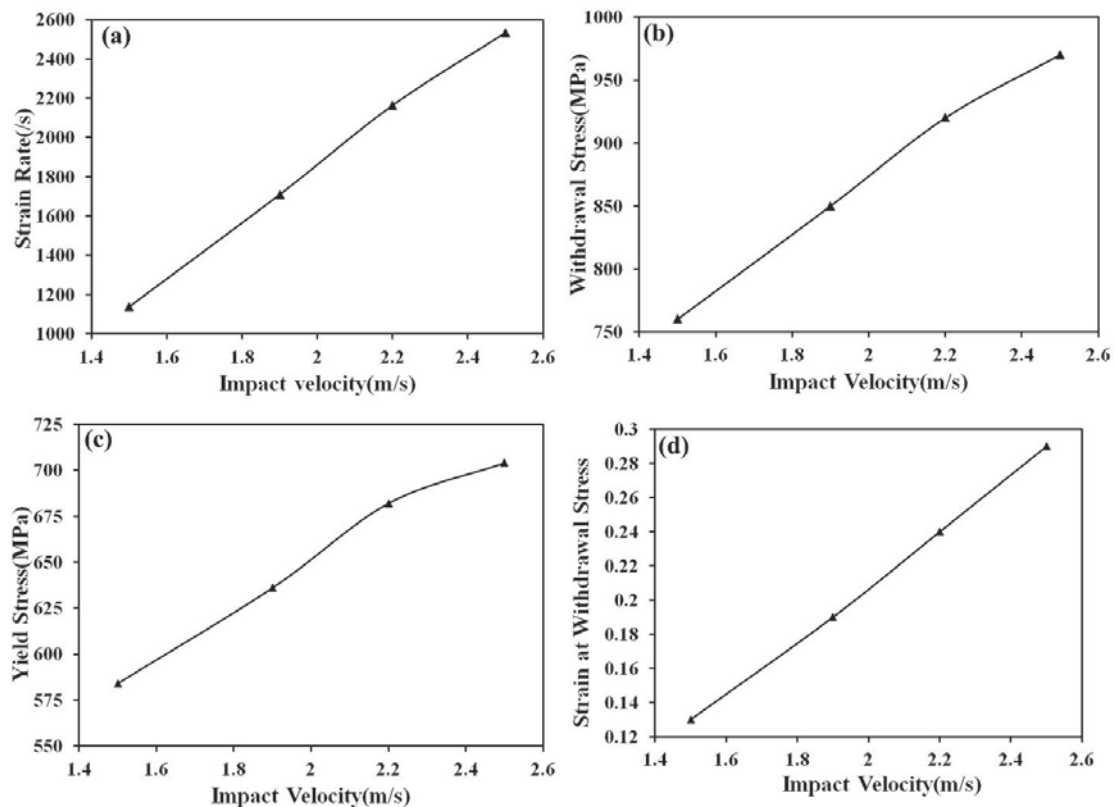| Load (kg/mm²)	Impact velocity(m/s)	Average strain rate (s⁻¹)	Average withdrawal stress(MPa)	Average strain at withdrawal stress	Average yield stress (MPa)
4	1.5	1138	760	0.13	584
6	1.9	1710	850	0.19	636
8	2.2	2164	920	0.24	682
10	2.5	2534	960	0.29	704

Figure 3(a-d). Impact velocity vs strain rate, withdrawal stress, yield stress and strain at withdrawal stress

From this figure it can be seen that the strain rate, withdrawal stress, yield stress and strain at withdrawal stress are varying proportional to the load. These values are increases with increasing impact velocity.

3.2. Slow strain rate deformation

3.2.1. True stress-strain behavior. The true compressive stress-strain curves for Aluminum 7075 alloy deformed at different strain are shown in fig.5 (a-d). The flow stress as well as the flow curve depends on the strain and strain rate. True stress-strain values were calculated from the engineering stress-strain value. As we know that, true stress, $\sigma_t = \sigma(1+\varepsilon)$ and true strain, $\varepsilon_t = \ln(1+\varepsilon)$ where σ=engineering stress & ε = engineering strain. After calculating value plot the true stress-strain curve which are below:
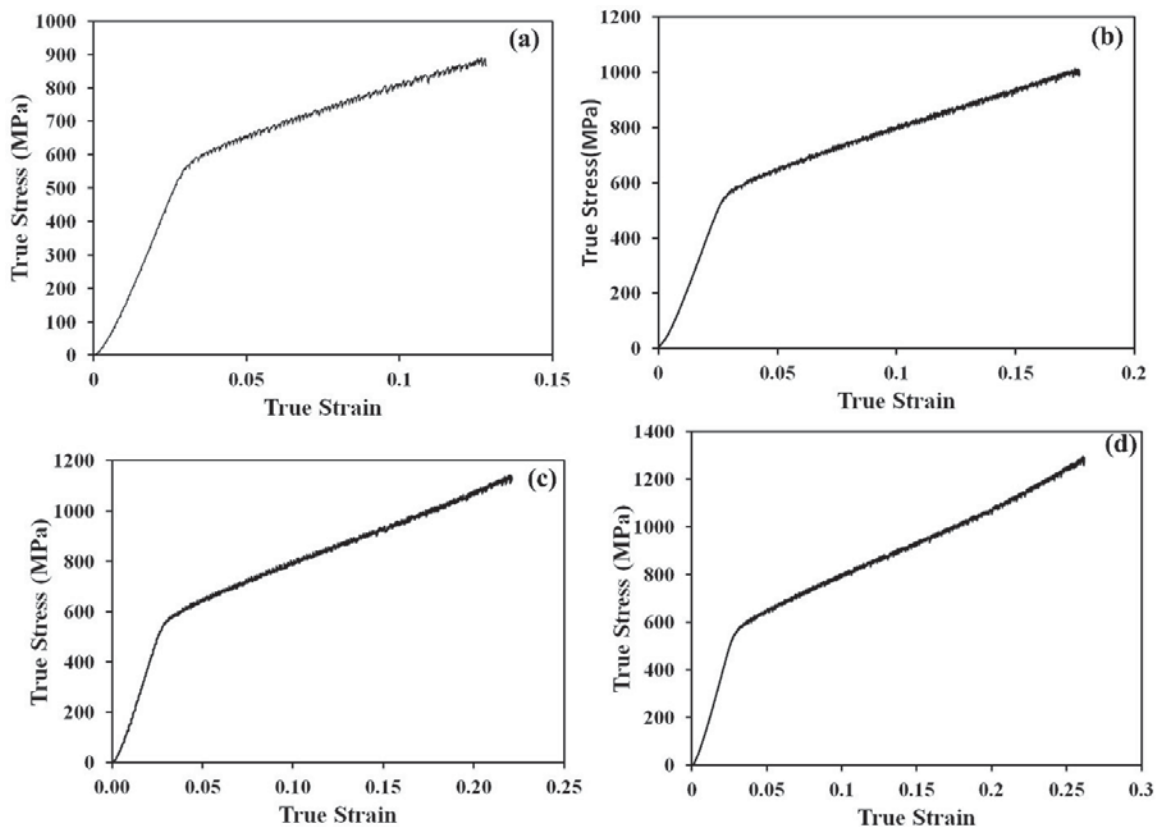
Figure 4(a-d). True stress-strain curves at different strain

3.2.2. n value calculation. The strain hardening exponents (n), determine the rate at which the materials hardens. If value of n increases the effect of strain on material strength and hardness also increases. The most important and widely used application is the evolution of stretch-formability by the n value. This value is calculated by the Holloman equation, $\sigma = k\varepsilon^n$ where, σ = true stress, ε = true strain, k = strength co-efficient. To determine the strain hardening exponents first calculate plastic strain and then taken log value of this equation. So, the equation will be: - $\ln(\sigma) = \ln(k) + n \ln(\varepsilon)$. From this equation we calculate the n values which are given below: 0.281, 0.312, 0.343, and 0.383 for various condition of strain.

Table 3. n value at different deformation load

Total strain	n value
0.13	0.281
0.20	0.312
0.25	0.343
0.30	0.383

3.3. Corrosion studies:

3.3.1. Immersion test. The corrosion rate and weight loss are obtained by the immersion test of the sample in 3.5 wt% NaCl for 30 days shows in the chart. It seems that corrosion rate decreases with increasing applied load and weight loss varies in irregular trend. As shown in figure (5 & 6) the corrosion rate is highest for 1.5 impact velocity and lowest for 2.5 impact velocity in both high strain rate & slow strain rate. This variation of corrosion rate shown in the following graph;

Table 4. Change in weight loss and corrosion after immersion test 3.5% NaCl solution

Immersion Samples	*Impact velocity (m/s)*	*Weight loss, Δw (g)*	*Corrosion Rate (m/y)*
High strain Rate test	1.5	5.01 – 2.09	312 – 270
	1.9	4.32 – 2.41	289 – 234
	2.2	4.14 – 2.04	275 – 254
	2.5	3.41 – 1.66	259 – 250
Slow strain Rate test	1.5	2.19	152
	1.9	1.91	141
	2.2	1.87	130
	2.5	1.41	113
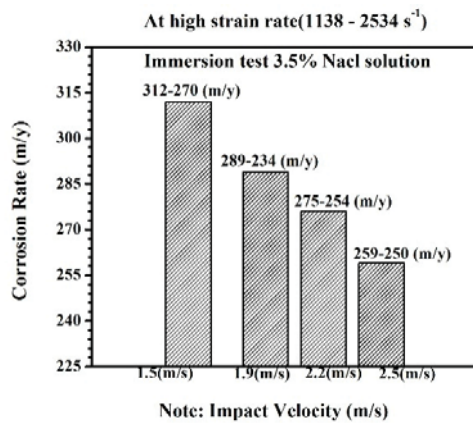
Figure 5. Impact velocity vs corrosion rate in immersion test after deform at high strain rate
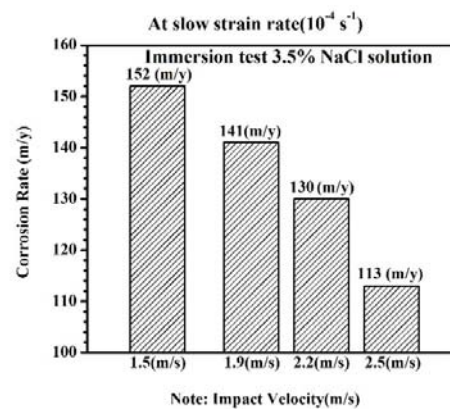
Figure 6. Impact velocity vs corrosion rate in immersion test after deform at slow strain rate

3.4. Microstructure Evolution

3.4.1. High strain rate and slow strain rate. The specimens after impact loading are examined by optical microscopy (OM) and scanning electron microscopy (SEM) in order to determine the effects of strain and strain rate on the evolution of the microstructure. Specimens were sectioned along cross-section or parallel to the applied load for SEM or OM. Specimen were polished in silicon carbide papers up to grit 1000 and also cloth polishing up to 0.1μ and immersed in pure ethanol for 1 min to dissolved water. Then those samples were etched using kroll's reagent (92 ml H_2O + 2 ml HF + 6 ml HNO_3). Fig.8. shows the microstructure of the specimen deformed at high strain rate between 1138 – 2534 s^{-1}. Under this condition, microstructure consist elongated grains in Al matrix. During high strain rate deformation micro voids are developed due to high strain and grow with increase in load. This micro void's coalescences are controlled by the localized plastic flow around them.
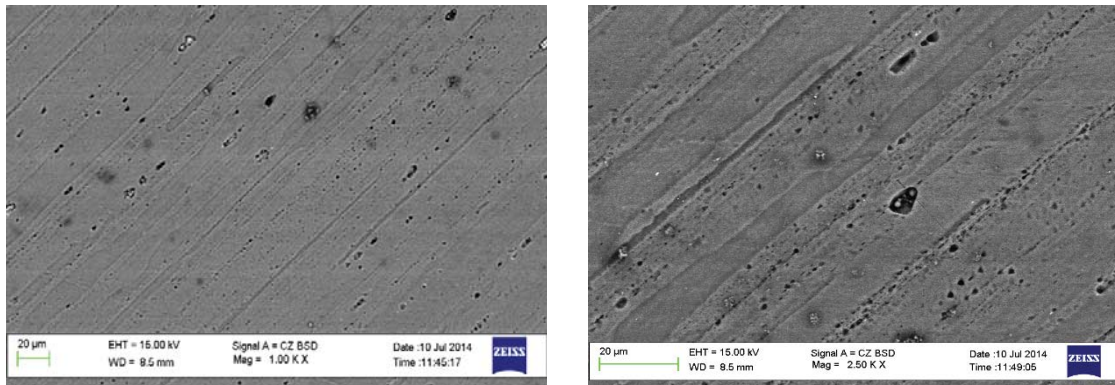
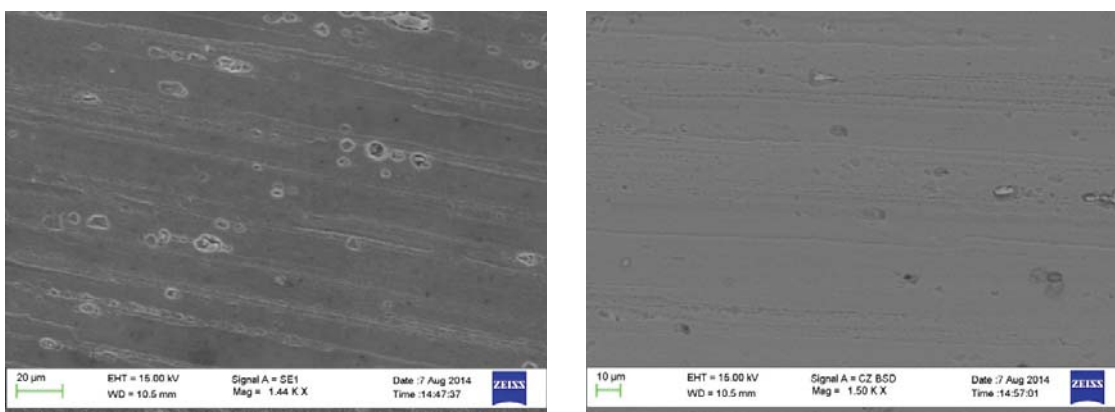**Figure 7.** SEM micrographs of the 7075 Al alloy deformed at high strain rates (1138 – 2534 s^{-1})

Figure 8. SEM micrographs of the 7075 Al alloy deformed at slow strain rates (10^{-4} s^{-1})

This figure shows the microstructure of the specimen deformed at slow strain rate at 10^{-4} s^{-1}. If the grain morphology is examined, it is found that the grains of the specimens compressed become more and more refined with increase in strain rate. This is due to the increasing dynamic recrystallization.

3.4.3. Corrosion Studies. The surface morphology of the 7075 aluminum alloy sample was examined by SEM immediately after corrosion tests in 3.5 % NaCl solution. SEM images of corroded sample given in Figs.10. show the formation of oxide on the surface of the sample after deformation on high strain rate and slow strain rate. The surface appears a typical localized corrosion. Corrosion products formed on the sample surface are distributed discontinuously. EDX analysis suggests that these corrosion products contain O, Na, Al, Cl, Zn.
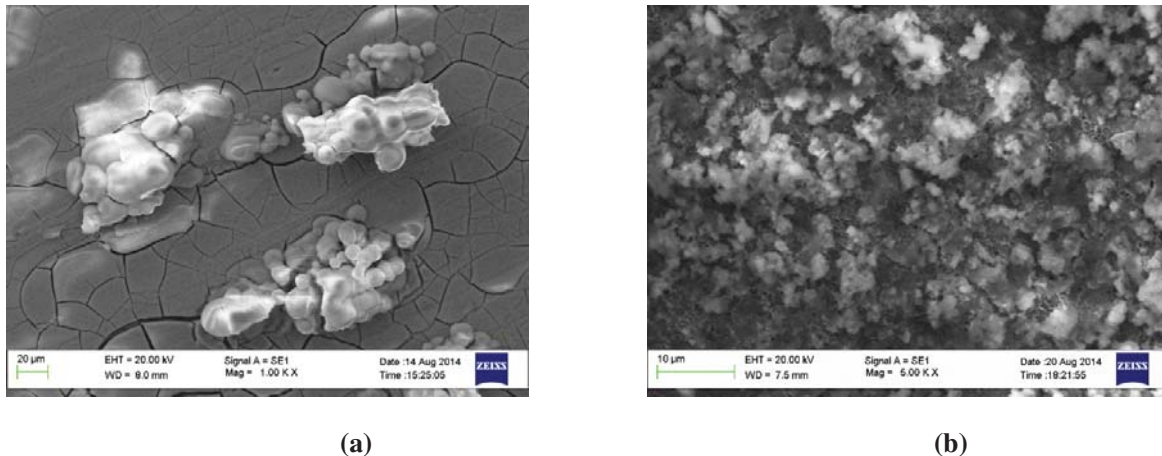
(a)   (b)

Fig 10. SEM micrographs of the oxide surface after immersion test in 3.5 wt% NaCl solution for 30 days in Secondary Electron mode: (a) High strain rate. (b) Slow strain rate

4. Conclusion

1. In high strain rate test the mechanical properties like yield stress, withdrawal stress increases with increasing load or impact velocity.

2. Elongated grains of Al along with fine precipitation are observed with microstructures with high strain rates.

2. In slow strain rate n value increases with increasing load.

4. The corrosion rate decreases with increasing load in immersion test in 3.5 wt% NaCl solution.

5. Reference

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