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Investigation of Strain energy release rate and Stress intensity factors in Slant edge pre-cracked Aluminium Plate

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Abstract- This research mainly describes the comparison of the strain energy rate of the two different materials (i.e., steel and aluminium). The aluminium can be replaced in spite of steel for in many applications. In the analytical study, pre-cracked three dimensional plate was loaded, The pre-crack was made in one edge of the plate in slant manner and outputs like strain energy release rate and stress intensity factors were taken for both the steel and aluminium.

Index Terms- Abaqus6.14, Finite element method, Strain energy release rate, Stress intensity factors.

I. Introduction

The material of the pre-cracked plate was taken as steel and aluminium (6061-T_6). The strain energy release rate was found for both the steel and aluminium (6061-T_6).Nowadays, in many of the structural engineering and mechanical engineering applications the steel was replaced by aluminiumalloy in the structures. The strain energy release rate is the important parameter in analyzing the behavior of crack in the material. J integral is the measure of the strain energy release rate. In this research the strain energy release rate was found out for the slant edge pre cracked plate. Aluminium itself is a silvery-white, lightweight metal, high thermal conductivity, has excellent corrosion resistance, it is having high malleable and ductile property. Aluminium with combination of other materials (alloy) is stronger than aluminium as the single material. The possible combinations of material with aluminium are with copper, manganese, magnesium and silicon. These alloy combination is lightweight but strong enough. Aluminium is also used in the manufacturing of aero plane parts. They are the second most available materials used in the construction industry after the steel. Steel is 34% heavier than aluminium. They are also less prone to brittle fractures. The applications of aluminium in various construction elements like sunshade, chimney, doors, shutters, window frames, window walls etc. Aluminium toughness is high with higher tensile strength. They can be fabricated in to many forms. Aluminium was used in the constructions like Empire state building, New York skyscraper. By using this aluminium as the construction materials in these types of structures, the cost of the building were minimized. In this Aluminium (6061-T_6) alloy, The proportion of various components in Aluminium (6061-T_6) is Al (95.8-98.6%), Cr (0.04-0.35%), Cu (0.15-0.4%), Fe (maximum 0.7%), Mg (0.8-1.2%), Mn (maximum 0.15%), Si(0.4-0.8%), Ti (maximum 0.15%), Zn (maximum 0.25%). Aluminium (6061-T_6) alloy is used in various applications like aircraft fittings, electrical fittings, marine fittings and hardware, camera lens mounts, couplings, connectors, magneto parts, brake pistons, hydraulic pistons, appliance fittings, valve parts and bike frames.These various useful applications are due to the excellent properties like excellent joining characteristics, good acceptance of applied coatings, relatively high strength, and good workability, highly corrosive resistant. The bending effects on the crack closure faces and the resulting effects on the SIF. A plate with a pre-existing crack is taken under the action of bending moment. This crack faces contact is induced by this bending, and it further introduces extra load along the crack extension. There are few if any experimental studies of fracture in plates subjected to bending, and in particular, cyclic loading of propagating cracks in such plates. Steel sheets were used as specimens and the loading was cyclic pure bending. In this central cracked, single edge cracked, Double edge cracked were modeled and analyzed. **[1]**. Local stress concentrations were used to develop frequently in the stiffened plate structures such as bridges, ships which are membrane tension and out of plane bending combinations. The cracks that initiate through the thickness of the plate, this is due to fatigue rapidly grow. Modern steels are highly resistant to brittle fracture; meanwhile if the cracks are not repaired, the fatigue may tend to speedy grow of cracks **[2]**. Slant edge types of cracks were found in the rails of the railway lines, the longitudinal section through a railway line, with a slant crack emanating from the running band. Such a crack is named a 'squat' **[3]**. It has been investigated that 0.65% of magnesium adding will help to increase the mechanical properties of aluminium alloy. If same magnesium is added in excess manner (i.e., beyond 0.71%), there will be decrease in the mechanical properties of the alluminium alloy **[4]**. Aluminium (6061-T_6) alloy were improved by controlling processing parameters. Aluminium (6061-T_6) alloy companied with Al_2O_3 and Si C_p .These companied specimen was poured into the steel and graphite moulds, these two are having wide range in cooling rates. The results were shown as that the hardness and the mechanical wear increased in the specimen, which was poured in to the steel mould. This is due to the increasing cooling rate in steel molds. The mechanical properties were decreased while using graphite molds due to decrease in the cooling rate. But the ductility was somewhat increased at some rate

When using the graphite molds, The yield strength increased with the increase in the percentage of Al_2O_3 and Si C_p. It was also found that the hardness increases in steel mold for specimen alloyed with SiCp particles whereas decreases with that alloyed in graphite mold **[5]**. The crack length may increase or decrease, it is depending upon the stress intensity factors K_I and K_{II} values. Thus the opening mode and shearing modes of crack is directly proportional to the crack length. If the main angle of the cracked plate increases, the rate of opening mode (KI) will decrease. The effects of the crack length to plate width ratio, crack inclination angle, crack location to plate height ratio on crack initiation angles were found. The first crack initiation angle mainly depends on crack length, crack location, and crack angle **[6].** Based on the viewed difference in fatigue delamination response, it is discussed that the fibre bridging generated during quasi-static and fatigue loading is different and normalization of fatigue data with quasi-static SERR becomes meaningless, strain energy release should not be imposed by the bridging fibre during fatigue delamination, unless they fail. Bridging fibres actually have little contribution to the SERR. Periodically storing and releasing strain energy is the main function of bridging and it is based on loading and unloading without permanent strain energy release. Only when failure occurs in bridging fibres, strain energy is permanently released from the bridging fibres. The SERR as commonly applied is not a worth criteria to study thew fatigue delamination growth **[7].** In the shaft, the slant edge crack was modeled, for a cracked rotor stiffness changes are only considered, which is a main parameter for structures to study the crack and the strain energy release approach and it is used to obtain the stiffness matrix. Coupling stiffness of bending–torsion, bending–tension and torsion–tension on the shaft is caused by the slant crack; coupling stiffness of bending–tension on the shaft is caused by the transverse crack **[8]**. In the present situation of high speed, high axle load railway system, the derailment of trains is a major failure in railway system. Among the several possibilities, track related problems were due to the cyclic load of train movement. The maintenance of the rails in the rural area was analyzed in Australia **[9]**. The derivation is based on the dynamic SIF of a surface crack subjected to an antiplane moving loading. Laplace transform helps in getting the solution to solve the transient response of a surface crack subjected to a dynamically antiplane moving loading. It is obtained by superposition of proposed fundamental solutions **[10].** The recent research told that the improvement of structural performance, weight and cost reductions are needed. The fracture toughness static strength, fatigue and corrosion resistance was achieved in the recent developments in high strength Al–Zn and Al–Li alloys. In Al–Cu, the research was under the damage tolerance and In Al–Li alloys the research were going on design and control of chemical composition. Improvement on mechanical properties, reduction of manufacturing, maintenance and repair costs, prevention of corrosion and fatigue and were the current research activities in the aluminium and their composites **[11]**.The mechanical properties of the aluminium 6061 was performed. With the help of the standard cylindrical compression specimens the compression properties of the alloy were determined. Hardness test was also conducted for the aluminium alloy using Micro-hardness Vicker's testing machine **[12].**

II. RESEARCH METHODOLOGIES

The slant edge crack was modeled and designed with the help of Abaqus 6.14(the unified FEA product suite offers powerful and complete solutions for both routine and sophisticated engineering problems covering a vast spectrum of industrial applications) by giving appropriate property, loading and boundary conditions(point load of 100N,boundary condition- pinned) to the specimen which was taken. At first, the datum lines were drawn with the help of spline for making the slant edge and partitions were made. After that the seam region and crack front portions were marked for the propagation of crack. The point load, which was the load condition given at the top mid partitioned line of the specimen and pinned boundary condition at the two ends.

Table 1: Input properties for the plate

Properties	**Steel**	**Aluminium ($6061\text{-}T_6$)**
Young's modulus	$2x10^5$ MPa	$68.9x10^3$ MPa
Poisson's Ratio	0.3	0.33
Density	$7.8x10^{-9}$ T/mm^3	$2.7x10^{-9}$ T/mm^3

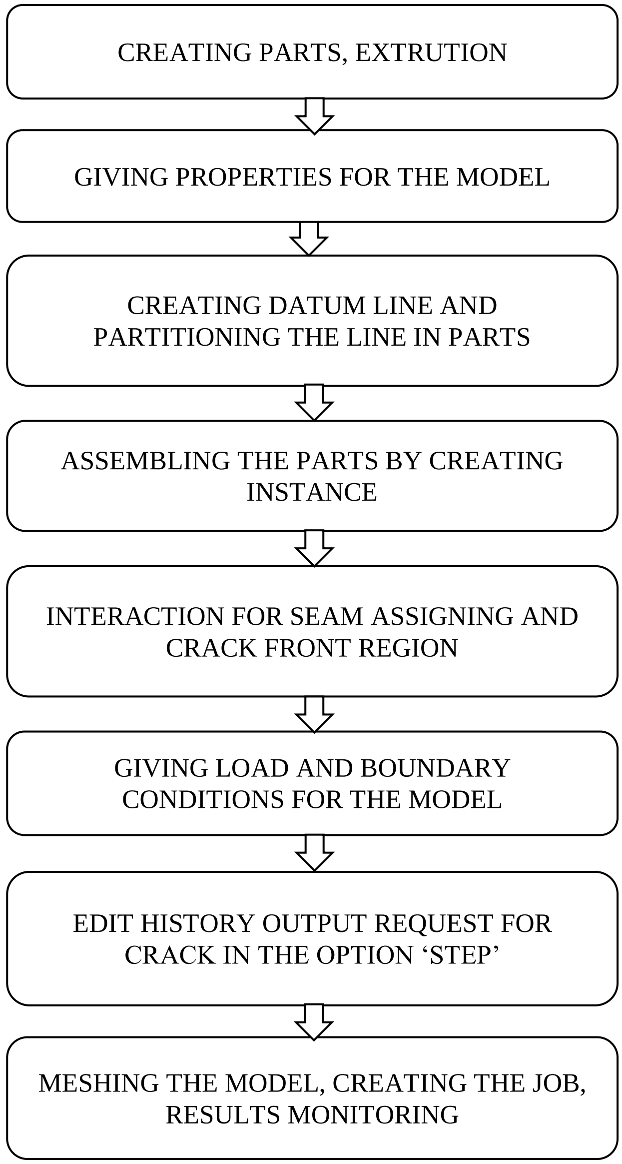

Fig 1: Flow of work in Abaqus

III. ANALYTICAL STUDY

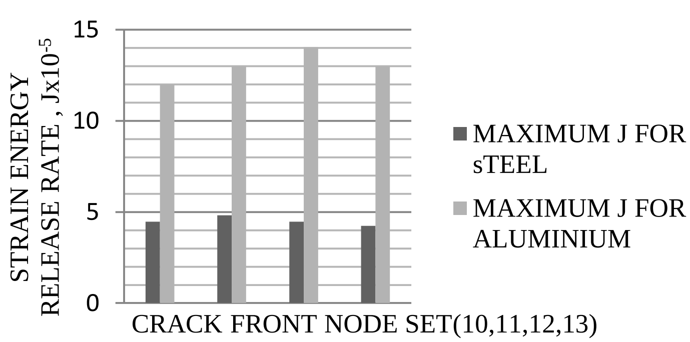

Fig 2: Comparison of max J value for both the materials

Table 2: Strain energy release rate and stress intensity factors for the material steel

MATERIAL	CRACK FRONT NODE SET	CRACK CONTOURS	J from Ks $X10^{-5}$		K1	K2	K3 $(X10^{-2})$
			MAXIMUM	MINIMUM			
STEEL	9	10	4.24	-	2.502	-1.750	-6.914
		8	-	2.51	2.342	0.157	-8.275
	10	10	4.47	-	2.820	1.372	-1.172
		2	-	3.15	2.638	0.104	0.631
	11	10	4.81	-	2.881	1.504	0
		8	-	3.25	2.674	0.107	0
	12	10	4.47	-	2.820	1.372	-1.172
		2	-	3.17	2.638	0.104	-0.631
	13	10	4.24	-	2.502	-1.750	6.913
		2	-	2.5	2.337	0.157	8.183

Table 3: Strain energy release rate and stress intensity factors for the material Aluminium (6061-T_6)

MATERIAL	CRACK FRONT NODE SET	CRACK CONTOURS	J from Ks		K1	K2	K3 $(X10^{-2})$
			MAXIMUM $X10^{-4}$	MINIMUM $X10^{-5}$			
ALUMINIUM (6061-T_6)	10	1	1.1973	-	2.482	-1.757	-8.153
		2	-	6.97	2.314	0.1645	-9.390
	11	10	1.3	-	2.844	1.401	-1.322
		2	-	9.15	2.658	0.106	0.7144
	12	10	1.4045	-	2.917	1.533	0
		2	-	9.44	2.701	0.107	0
	13	10	1.3	-	2.844	1.401	-1.3
		2	-	9.15	2.658	0.106	-0.794
	14	10	1.1973	-	2.482	-1.757	8.154
		2	-	6.97	2.314	0.1645	9.39

IV. RESULTS

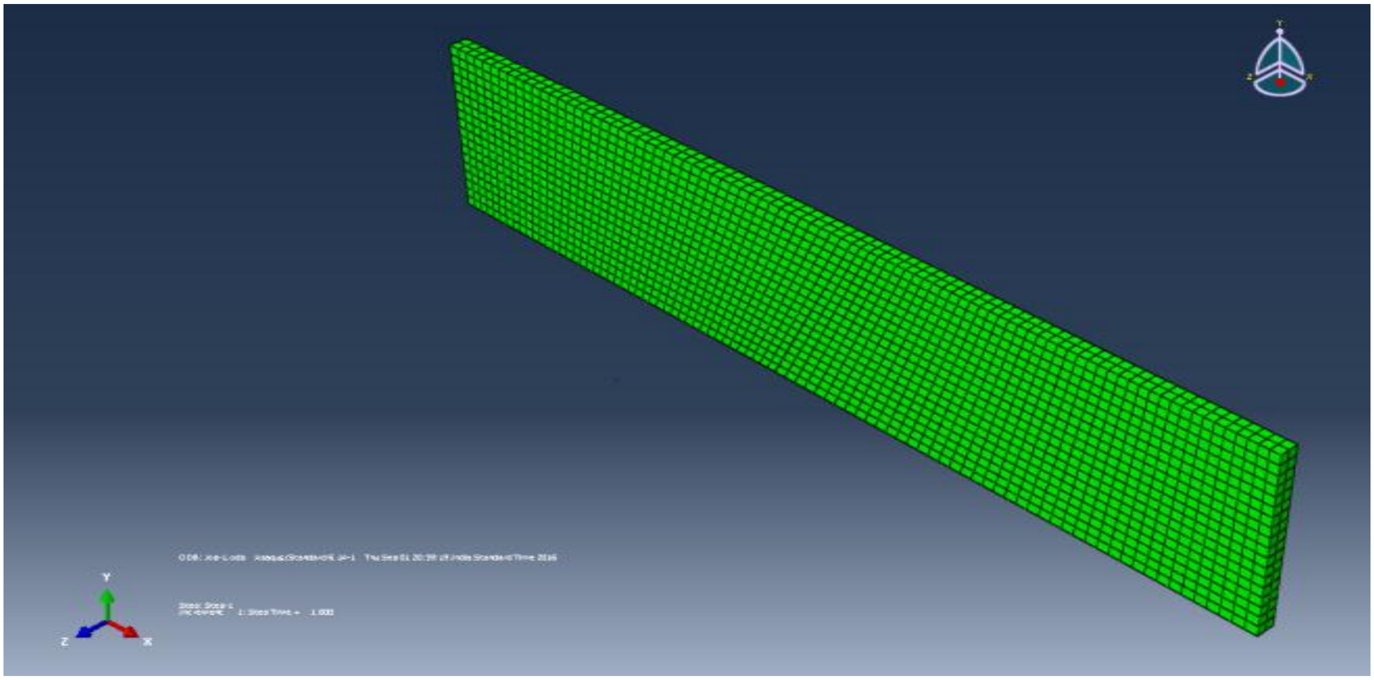

Fig 3: Meshing of plate

Table 4: Slant edge cracked plate

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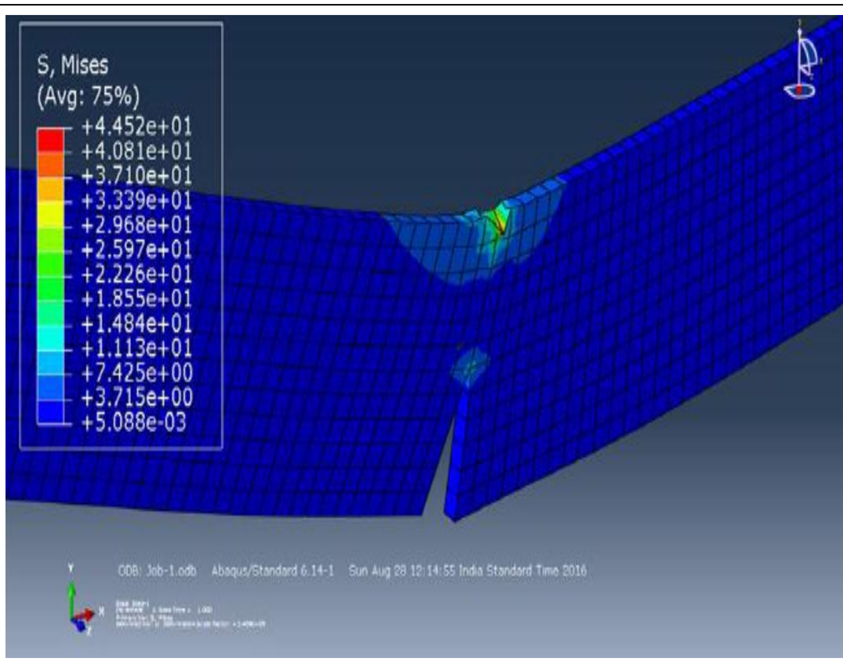
<td>

Fig 4:Slant edge cracked plate</td>
<td>In most of the investigations, The Slant edge type of cracks should fail in tearing mode</td>
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V. CONCLUSION

The contour integral was given as the input in abaqus, several parameters like strain energy release rate and the stress intensity factors were given as the history output reques. Strain energy release rate is maximum for the aluminium (6061-T_6) than the steel. It is essential to know that the critical crack length is an absolute number and it is not depending on the structure's size. When the crack length is a, If the crack length changes from 'a' to 'δa' then there will be some increase in the strain energy release rate. The young's modulus of aluminium and aluminium related alloy is lesser than steel. The young's modulus directly depends upon the tensile strength of the specimen. But the aluminium alloy is preferred in many high rise buildings and aircraft parts due to their light weight and high strength. Thus, the study was achieved in comparing the fracture parameters of both the steel and aluminium alloy. On comparing with the amount of energy dissipated for steel, the amount of energy dissipated for aluminium (6061-T_6) is maximum. From the table we can see, the stress intensity factor for third mode varies in higher values, therefore this type slant edge crack comes under the tearing mode. The aluminium itself is the weaker material, which cannot be used as the elements in structures.so by combining the aluminium with some alloys, it becomes very stronger. In many structures like skyscrapers, the aluminium alloys were used in the areas where there is the necessity to reduce the weight of the members. This is the reason for choosing the aluminium (6061-T_6) in this research; the strain energy release rate is higher for aluminium alloy than steel. Due to this reason aluminium alloys were not used to implement in the high load carrying capacity members. These aluminium alloys were used in the structures like windows, roofs, building facades. The usage of steel in these elements will increase the cost and the weight too. The further research is significantly expected in the fracture related problems in aluminium alloys which are used in the structural elements.

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