EFFECT OF BAND OVERLOAD ON FATIGUE CRACK GROWTH RETARDATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Effect of Band Overload on Fatigue Crack Growth Retardation

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CERTIFICATE

This is to certify that the project thesis entitled, "Effect of Band Overload on Fatigue Crack Growth Retardation " submitted by Kaustav Moni Saikia, Roll No. 10503036, Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out by him under our supervision and guidance.

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ABSTRACT:

The present investigation studies the effects of a band overload (multiple overloads) on fatigue crack growth. It has been observed that a tensile overload tends to reduce the rate of a fatigue crack growth. The multiple-overloading, hence, is investigated for its effect on the fatigue crack growth. The specimen material is Aluminum 2024 T3 and a push-and-pull type servo-hydraulic fatigue testing machine INSTRON 8502 was being used to conduct the experiments. The crack growth was measured manually by the use of 1 mm graduations marked on the specimen itself. The notch was further sharpened with a jeweler's saw. The specimen was being outsourced from HINDALCO. To study the effect of band overloads (multiple overloads), we applied overload cycles of 100, 10, 5 and 2. The graphs were being plotted and compared to that of data collected from single spike overloads.

NOMENCLATURE

K	Stress intensity factor
K_{max}	Maximum stress intensity factor in a cycle
$K_{min\_}$	Minimum stress intensity factor in a cycle
ΔK	Change in Stress intensity factor in a cycle
σ_{ij}	Stress in ij plane
r	Size of plastic zone
$d(a)/dN$	Crack growth rate
C &m	Paris material constant
σ_o	Stress at crack opening
σ_{max}	Maximum stress in a cycle
ΔK_{eff}	K_{max}-$K_{opening}$
a_d	Retardation in crack length
N_d	Retardation in number of cycle
a	Crack length

R^{OL}, or O.L.R	Overload ratio
F_g	Geometric correction factor for specimen
ΔP	Change in load in a cycle
K_{IC}	Plastic strain fracture toughness
E	Young's Modulus
σ_y	Yield strength of material
M'	Specific growth rate
N	Number of cycles
R^t	Temperature ratio
K^{Ol}	Stress intensity factor at overload

INTRODUCTION :

Metal Fatigue is a process, which causes premature failure or damage of a component or structure due to repeated loading. Fatigue failure is particularly insidious because it occurs without any obvious warning.

Three basic factors are necessary to cause fatigue failure. They are :

a. A maximum tensile stress of sufficiently high value.

b. A large enough variation or fluctuation in the applied stress.

c. A sufficiently large number of cycles of the applied stress.

In addition, there are a host of other variables, such as stress structure, residual stresses and combined stresses, which tend to alter the condition to fatigue.

There are three methods for fatigue analysis stress life approach, strain life approach and the fracture mechanics approach. These methods have their own region of application with some degree of overlap. Fatigue process can be generally be broken into two distinct phases- initiation and propagation. The initiation encompasses the development and early growth of a small crack. The propagation is the portion of total life spent growing a crack to failure.

Fatigue crack growth can take place under constant amplitude loading or variable amplitude loading condition. In contrast to constant amplitude loading where the increment of crack growth, a is dependent only on the present crack size and applied load. Under variable amplitude, loading the increment of fatigue crack growth is also dependent on the preceding cyclic loading history. This is termed as load interaction. The load interaction affects significantly the fatigue crack growth rate and consequently fatigue lives.

The structural materials are inherently flawed and fatigue life is the time or the number of cycles required to propagate a dominant flaw. Catastrophic failure is preceded by a substantial amount of stable crack propagation in metallic material when subjected to cyclic loading.

Application of tensile overloads during fatigue crack propagation causes a decrease in crack growth rate and correspondingly an increase in the specimen life; thus knowledge of overload is of considerable interest to aircraft engineers. The literature available till date indicates that the application of overload results in appreciable retardation in crack growth rate which has been explained by several concepts. These include fatigue failure crack closure, compressive residual stresses crack tip blunting, strain hardening, etc the mode I overload effect has been established by Bernard et al. studied the mode I overload effect and reviewed the empirical relations and suggested a relation which accounts for the closure.

Fatigue in metals can be defined as failure of member due to the application of repeated and/or fluctuating loads which are far less than that of static strength of member. Due to cyclic plastic deformation arisen from the application of cyclic fluctuating or repeated loading, cracks will develop at micro defects.

Failure of member under fatigue loading can be classified into five steps based on crack propagation as mentioned below:

1.Crack nucleation caused by sub structural and micro structural changes.

2.The creation of microscopic cracks

3.Formation of dominant crack from the movement of dislocations and slip bands which eventually lead to cat strophic failure.

4.Stable propagation of dominant crack so produced.

5.Structural instability and complete failure of member.

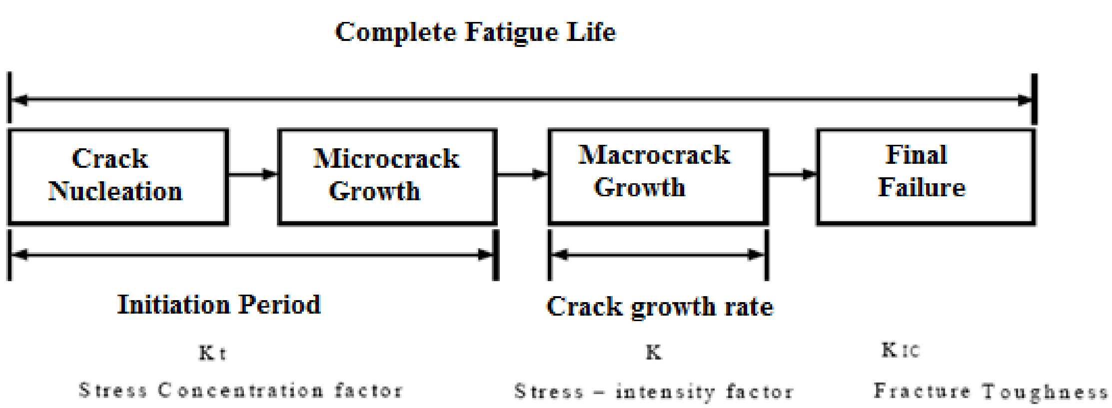

Figure 1.1 Different stages of fatigue crack growth

2 LITERATURE SURVEY:

2.1. FATIGUE CRACK INITIATION THEORIES:

The process of fatigue crack initiation is highly complex and depends greatly on the plastic strain amplitude, the temperature, the deformation characteristics of the material (dislocations) and the material microstructure.

For generalization, the process may be subdivided into the following events:

1. Generalization or annihilation of the redundant dislocation density through fatigue hardening or softening to form a cyclically stabilized dislocation population.

2. Localization of slip through the formation of constrained dislocation substructure, like persistent slip bands (PSB), dislocations cells or planer dislocation arrays, on further cyclic.

3. Interaction of this dislocation substructure with a free surface to produce extrusions and associated intrusions on it.

4. Concentration of stresses by such intrusions to produce embryonic cracks.

It must be pointed out that the events outlined above have merged from laboratory studies on homogenous, single phased materials mainly. In complex engineering materials, and in components, stress concentrators may be present from the outset, in the form of inclusions, casting or welding defects, grinding or machining marks for example, cracks are found to initiate from grain boundaries only after incompatibility of slip exists across such boundaries and irreversible grain boundary sliding can occur. Similarly, the stress concentrations produced by an inclusion localizes the slip processes, which ultimately lead to the formation of a micro-crack through, de-cohesion of the inclusion- matrix interface or by cracking of the inclusion itself. Sometimes crack-like defects may lead to propagation of the crack straight away without any need for initiation.

The model of crack initiation by localization of cyclic slip cumulates in the formation of an intrusion which, acting as a stress concentrator, nucleates an embryonic crack. However, the exact process by which an intrusion is transformed into a crack is a matter of debate. There is quite some inclination not to distinguish between an intrusion and a micro-crack and to consider the cracking process as an extension of that which formed the intrusion itself. Local brittle fracture ahead of an intrusion due to concentration of stress has been as another possibility. Condensation of vacancies generated during cyclic deformation on an intrusion has also been proposed, although fatigue crack initiation at as low as -270 C. Amongst the other notable mechanisms that has been proposed are loss of coherency across slip planes due to defect accumulation and plastic occurring on a micro-scale at the root of an intrusion.

2.2. FATIGUE CRACK GROWTH THEORIES:

The initial stage ends with the formation of a micro-crack which usually lie along activated slip planes (inter-granular cracks being exceptions), and are often numerous in any instance. Further growth of these cracks being cyclic loading occur through two distinct stages- stage I and stage II, leading ultimately to complete failure of the many micro-cracks that exist simultaneously in a body, some do not propagate through stage I before arresting or coalescing with to other cracks, while usually a single micro-crack grows to failure. The selection process involved in this phenomenon is governed by the activation available to each of the slip system from the applied loading.

Stage I cracking is essentially extension of the microcracks along their habit planes, and therefore crystallographic in nature. Stage II propagation is typically non-crystallographic and occur in a direction that is normal to the applied tensile stress axis. Because slip is a shear process, slip planes that are proximate to the planes of maximum shear in a component (+45 or -45 to the axis in an uniaxial test specimen) usually support stage I growth. Hence, the stage I crack propagation is thought to be controlled by the shear component of the applied stress while stage II cracking is controlled by the tensile component. However, experiments by Kaplan and Laird in which artificial Stage I crack failed to grow in copper single crystal in compression (which would have the same shear component as a tensile loading), illustrated the importance of the tensile component of stress to the growth of Stage I cracks also.

Stage I cracks usually grow through a few grains diameters before deviating gradually into a stage II crack. Various causes for the transition has been proposed – obstacles to easy glide blocking the crack tip, like an unfavorably oriented grain, conditions of constraint in the depth restricting slip due to a low shear stress to tensile ratio.

Crack tip displacement accompanying the crack tip blunting the tensile straining exceeding the dislocation substructure etc. generally lower stresses and low mean stress, preferred orientations in the microstructure of a material and the corrosive conditions promote circumstances Stage I growth may lead to final fracture.

The surface of a stage I crack has a faceted appearance as the crack-path tilts on crossing grain boundaries. The surface of the stage II crack is characteristically covered with parallel markings at the intervals of 0.1 m or more called striations which are supposed to be successive positions of the crack front. The formation of the intimately connected with the micro-mechanisms of fatigue crack propagation.

Crack propagation in stages I and II is thought to be continuum controlled growth and is therefore relatively insensitive to the microstructure of the material. However, once the crack length increases sufficiently and incremental extensions are of the order of the defect or particle spacing in a material, simple continuum behavior is interrupted. Secondary cracking, void formation and other static fracture mode become increasingly and crack growth occurs by combination of stage II continuum controlled processes and these static modes. Such a state of growth becomes exceedingly important in characterizing fatigue life of components made of high strength materials and those operative at high temperatures.

2.3. <u>MICROSCOPIC STAGES OF CRACK GROWTH:</u>

On further application of cyclic loading the dislocations and irregularities that were present in the component will increase their severities in the vicinity of nucleated crack which finally leads to the formation of a dominant crack. The crack propagation due to the application of cyclic loading can be divided into two stages :

1. ***Stage I crack growth***

The zigzag crack path that has been formed due to single shear of slip planes is termed as stage I crack propagation. In ductile solids, cyclic crack growth can be visualized as a process of intense localized deformation which tends to creation of newer crack surfaces. The direction of propagation of crack will be approximately $45\_^{0}$ to the direction of load application. It will propagate for two to three grain boundaries.

2. ***Stage II crack growth***

As crack propagates the crack tip compromises of many grains. Because of this simultaneous slip planes will develop which will lead to *stage II* crack propagation. In single crystals the transformation of *stage I* to *stage II* causes to the formation of dislocation cell structures and the breakdown of PSB's at the crack tip.

During *stage II* crack propagation the direction of crack growth will be almost perpendicular to the direction of application of load. The fracture surfaces created by stage II crack propagation is generally characterized by striations. For certain values of imposed cyclic loads in Paris regime of fatigue crack advance, it has been found that the spacing between adjacent striations correlates with experimentally measured average crack growth rate.

Different mechanisms were proposed to explain the *stage II* fatigue crack growth. One among them is Plastic blunting mechanism proposed by Laird [1]. In this mechanism the crack extension is supposed to be occurred due to plastic blunting of crack tip. This model can be applied to almost all ductile materials. Another mechanism is based on strain hardening in the formation of duplex slip bands. Work hardening in primary slip will increases crack resistance which let the crack to find another nearby slip plane which will have less resistance. Thus crack will now propagate on second plane. Kinematic irreversibility of cyclic slip causes a net crack growth in a planer fashion along the line of intersection of two planes.

2.4. DIFFERENT REGIMES IN CRACK GROWTH:

Current theoretical and experimental linear elastic approaches tries to describe the stable and unstable crack growth by a crack propagation rate which can be defined as incremental crack growth da divided by increment in number of load cycles dN. This fatigue crack growth rate can be correlated with stress intensity factor according to Paris law given by where c and m are material constants and $\Delta K = K_{max} - K_{min}$. If a graph is drawn between and log (ΔK) it will be as shown in fig 1.3. This figure can be divided in to three regimes.

Region I*:* This region is characterized by an increase in asymptotically with log (ΔK). Crack can't be initiated until and unless ΔK reaches certain threshold value known as ΔK_{th}. Below this the increase in da/dN is very low that can't be measured experimentally. This regime is generally contributed by crack nucleation and early growth state. Above threshold da/dN will increase in a steep manner.

Region II: It is also called as Paris regime in which there is a linear variation of vs. log (ΔK). This region is characterized by stable crack growth.

Region III: This region is characterized by rapid crack growth rates. And the maximum stress intensity factor of the cycle reaches to fracture toughness K_{IC} of material.

2.5. CRACK RETARDATION BY OVERLOADING:

Crack is an unavoidable yet major source of failure in most of mechanical components. If the stress intensity factor at the crack tip is crossed threshold value the crack propagation will be initiated and will leads to final failure. Once if the crack has crossed regime II i.e., stable crack growth and enters into regime III there will be rapid crack growth rate which will not leave even sufficient time for the component to get replaced (for components like gas turbines it will take years to gather to manufacture a new one and is also cost worthy). So all thing that can be done is to retard crack propagation before crossing regime II so that there will be sufficient time for a component get replaced and operating cost can be get minimized.

Till date different techniques were proposed to retard the crack growth rate. One important technique that is available for retardation is application of overload spike over normal operating cyclic loading.

As present study is to find the effect of overload in combination with low temperature further of this chapter will deal with effect of overload spike on crack growth. During normal cyclic loading if an overload spike is applied as shown in fig 2.1 the crack growth rate is found to be decreased. During and after the application of overload spike following things can be observed.

The ductile solid generally exhibits a temporary accelerated crack growth rate during and immediately after the application of overload In post overload regime, for same amount of base line stress intensity factor ΔK_B there will be a deceleration in crack growth rate. After reaching to a minimum, crack growth rate will again start increasing and finally after certain delayed number of cycles it will again reaches to base line crack growth rate. The crack length at which the crack growth rate reaches minimum is generally known as delayed distance a_d.

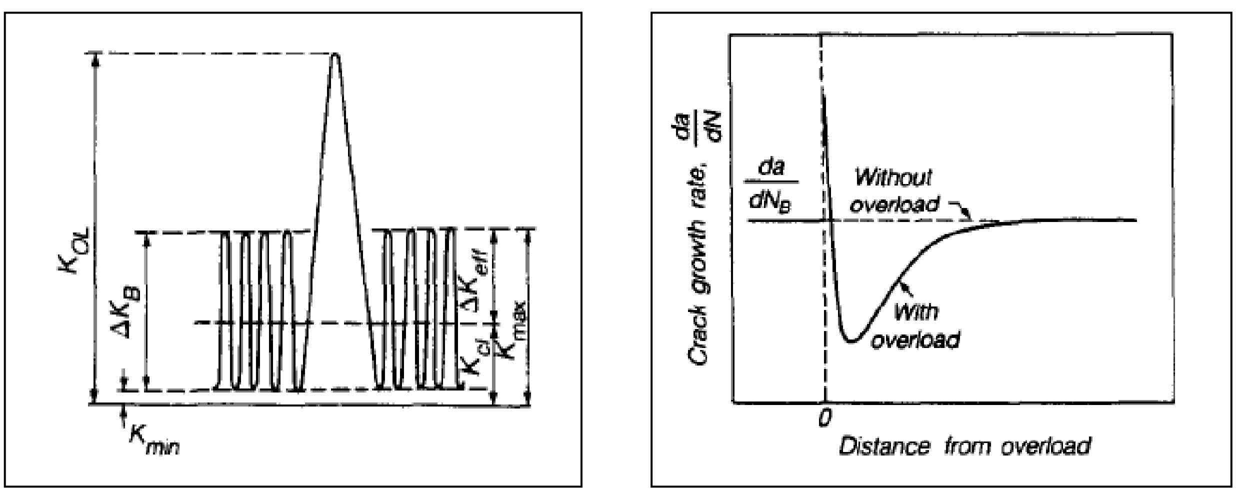

Fig 2.1 Effect of Overload Spikes

2.6. FACTORS INFLUENCING FATIGUE CRACK GROWTH:

LOADING PARAMETERS:

Loading parameters like ΔK, ΔK_{max} and R influences the FCGR significantly. For example, for a constant ΔK more positive is the stress ratio R higher is the crack growth rate [6, 7]. However, the stress ratio sensitivity is material dependent. Similarly, at a given R, the crack growth increases with $K_{max.}$

ENVIRONMENTAL EFFECTS:

The fatigue crack growth rate can be greatly influenced by environmental effects. Their effects are extremely complicated due to the large no of mechanical, metallurgical and chemical variables and the interaction between them.

In hostile environment, frequency of load cycle has significant effect on FCGR. At low frequencies , crack growth rates increases as more time is allowed for environmental attack during the fatigue process.

Reduced fatigue life is usually observed with increasing temperature. In addition at elevated temperature environmental effects are usually greater.

The environmental effects have also been observed to cause either an increase or decrease in ΔK may be explained in some cases by local corrosion or oxide formation on the crack surfaces contributing to the crack closure effect.

LOAD INTERACTION EFFECTS:

In case of fatigue crack propagation there is a large interaction effect of cycles of different amplitudes. The application of a single overload cycle is observed to cause a decrease in the crack growth rate and the phenomenon is termed as crack growth retardation. If the overload is large enough crack arrest may occur and the growth of the fatigue crack may stop completely.

2.7. FATIGUE CRACK CLOSURE:

The fatigue crack closure phenomenon is very common in fatigue loading under constant and variable amplitude loading condition. It is a key physical phenomenon under variable amplitude loading condition and also in the presence of reactive environment. The role of crack closure is also very significant in case of short cracks and for crack growth in the threshold region.

The concept of crack closure was first reported by Elber. Elber proposed that crack closure occurs as a result of crack tip plasticity. A plastic zone develops around the crack tip as the yield stress of the material is exceeded. With the crack growth, a wake of plastically deformed material develops while surrounding body remains elastically deformed. Elber proposes a fatigue crack in a body subjected to a tension tension loading cycle is completely open only at higher load levels. On that part of the loading cycle during which crack is fully open contributes to the crack growth. The stress and the stress intensity factor corresponding to this loading are known as crack opening stress and crack opening stress intensity factor respectively.

Fatigue crack growth in ductile alloys is dominated by the cyclic plastic deformation that occurs ahead of the propagating crack resulting in the plasticity induced crack closure. This reduces the actual available stress intensity factor range from ΔK to $\Delta K_{eff.}$

Three important mechanisms of crack closure are:

1. **Plasticity induced closure:**

   During the growth of fatigue crack the crack tip plastic zone increases in size. On unloading residual compressive plastic strain develops at the crack tip. This plastic zone over the crack length is refined as the plastic wake[8]. Since ΔK increases with crack growth for most geometries under constant load amplitude condition, the plastic wake increases with the crack growth. In no load condition strain mismatch produces residual compressive stresses over the plastic wake. This transmits the compressive stresses normal to the crack surfaces and thus keeps the two crack surface pressed and close together.

2. **Oxide induced closure:**

   In a reactive environment a newly created fatigue fracture surface gets oxidized and corrosion products build up [9,10]. The product of corrosion effectively impedes crack growth in a manner similar to plastically induced closure. The oxide induced closure arises when the thickness of the corrosion product near the crack tip is comparable to CTOD.

3. **Asperity induced closure:**

   Walker and Beevers [11] reported that an irregular or rough fracture surface morphology has a significant effect of crack closure.

2.8. RETARDATION PARAMETERS AND KINETICS OF CRACK GROWTH IN OVERLOADING:

CRACK PROPAGATION BEHAVIOR AT OVERLOADING:

Fatigue crack growth tests and predictions performed under constant amplitude loading often differ considerably from variable amplitude loading conditions. In constant amplitude loading increment of crack, a depends only on the present crack size and applied load whereas under variable amplitude loading increment of fatigue crack growth is also a function of the proceeding cyclic loading history. There is a large interaction effect of cycles of different amplitude in fatigue crack propagation [12]. Crack growth retardation is caused by application of tensile overload over a constant amplitude fatigue test.

Following observations may be made in the sequence given below on overload applications.

a. Acceleration in crack growth.

b. Decrease in crack growth rate to the minimum.

c. Increase in crack growth rate up to the pre-overloaded crack growth rate.

The effect of retardation is mostly expressed by following parameters:

N_D = Total number of cycles involved during retardation.

N_{D*} = no. of cycles to minimum crack growth rate.

A_D = Overload affected total crack length

A_{D*} = Crack length corresponding to minimum crack growth rate.

POST OVERLOAD CRACK CLOSURE:

The overload introduces a plastic zone and due to this residual compressive stresses develop at the crack tip. The residual compressive stresses are responsible for crack closure. The crack closure takes place over a length longer than that in constant amplitude condition. Crack growth starts only if residual stresses are overcome to a degree that crack tip is open again. This explains the low growth rate of the crack on tensile overload application. Immediately after overloading, there is no closure condition due to crack tip blunting [13]. Closure increases to the maximum value, which is reported as crack closure corresponding to the overload. The effect of crack closure on the post overload retardation behavior has been studied by several investigators.

OVERLOAD AFFECTED CRACK LENGTH:

It is observed by several investigators that the overload affected crack length; a_D is associated with monotonic plastic zone at the crack tip. Bathias and Vancon [14] observed that a_D is 25% to 60% of the overload induced plastic zone in Al alloy. Rangnathan[15] et. al. reported for Al alloy that a_D is nearly equal to the overload induced plastic zone in the plain stress condition.

A few investigators reported for different alloys that a_D is several times greater than monotonic plastic zone (PZS) at the plastic tip. Some investigator have shown that a_D increases with PZS.

From the above information it is clear that there is no general agreement between a_D and monotonic PZS. It is reported by a few workers that a_o and a_{o*} increase with OLR. Ranganathan et al have reported that plastic zone increases with OLR and SIF range and K.

2.9. FATIGUE CRACK GROWTH CURVES:

In constant amplitude fatigue loading conditions the crack length increases with the number of cycles. The crack length a vs number of cycles is shown in the figure below. Figure 2.1 shows most of the loading cycles involved in the total life of engineering component are consumed during the early stages of crack extension, when the crack is very small.

Fatigue crack growth is determined from the curve either by graphical procedures or by computation. In a constant amplitude fatigue test crack growth rate increases with increasing crack length.

To study the crack propagation crack growth rate, da/dN is plotted against stress intensity range, Del K is defined as:

$$K = f(g) . \frac{F\sqrt{\pi a}}{wB}$$

$$\text{where, } f(g) = 1.12 - 0.231(a/w) + 10.55(a/w)^2 - 21.72(a/w)^3 + 30.39(a/w)^4$$

……………… eqn 2.1

where, f(g) is a function of specimen and loading geometry.

A typical plot of log da/dN vs logΔK has a sinusoidal and can be divided into three regions. At lower stress intensity range, the crack extension is associated with threshold stress intensity factor, ΔKth below which there is no observable fatigue crack growth. In the mid-region the curve is essentially linear. Finally at high ΔK values crack growth rates are extremely high and little fatigue life is involved.

3. EXPERIMENTAL:

3.1 MATERIALS AND FABRICATION:

Specimen Material:

Aluminum alloys find extensive applications in transport industries, aerospace industries, defence and for consumer durables due to their higher strength to weight ratio, corrosion resistance and high ductility. The material investigated in this study is Al 2024 T3 alloy in procured from HINDALCO, Renukoot (Mirzapur). The chemical composition and tensile properties are given below in table 3.1.

Table 3.1

CHEMICAL COMPOSITION FOR TESTED ALLOY (WT%)

Alloy	Cu	Mg	Si	Mn	Zn	Cr
2024 T3	4.5	1.5	0.5	0.6	0.35	0.1

Table 3.2

TENSILE PROPERTIES OF AL- ALLOY

Alloy	Yield Strength MPa	Ultimate Tensile Strength MPa	% Elongation	Strain Hardening Exponent n
2024 T3	4.5	1.5	0.5	0.6

3.2. TEST SPECIMENS :

The single edge cracked tension specimens have been used for fatigue test in the present investigation. For this purpose, specimens have been sheared with their longitudinal axis parallel to the rolling direction of the sheet with width equal to 50mm and thickness equal to that of the sheet thickness.

The samples have been polished and graduated at an interval of 1mm. The specimens have been further given a flat notch of 13.5 using milling and then notch sharpened to a length of 15.3 using a fine jeweler's saw.

3.2 SPECIMEN DIMENSIONS :

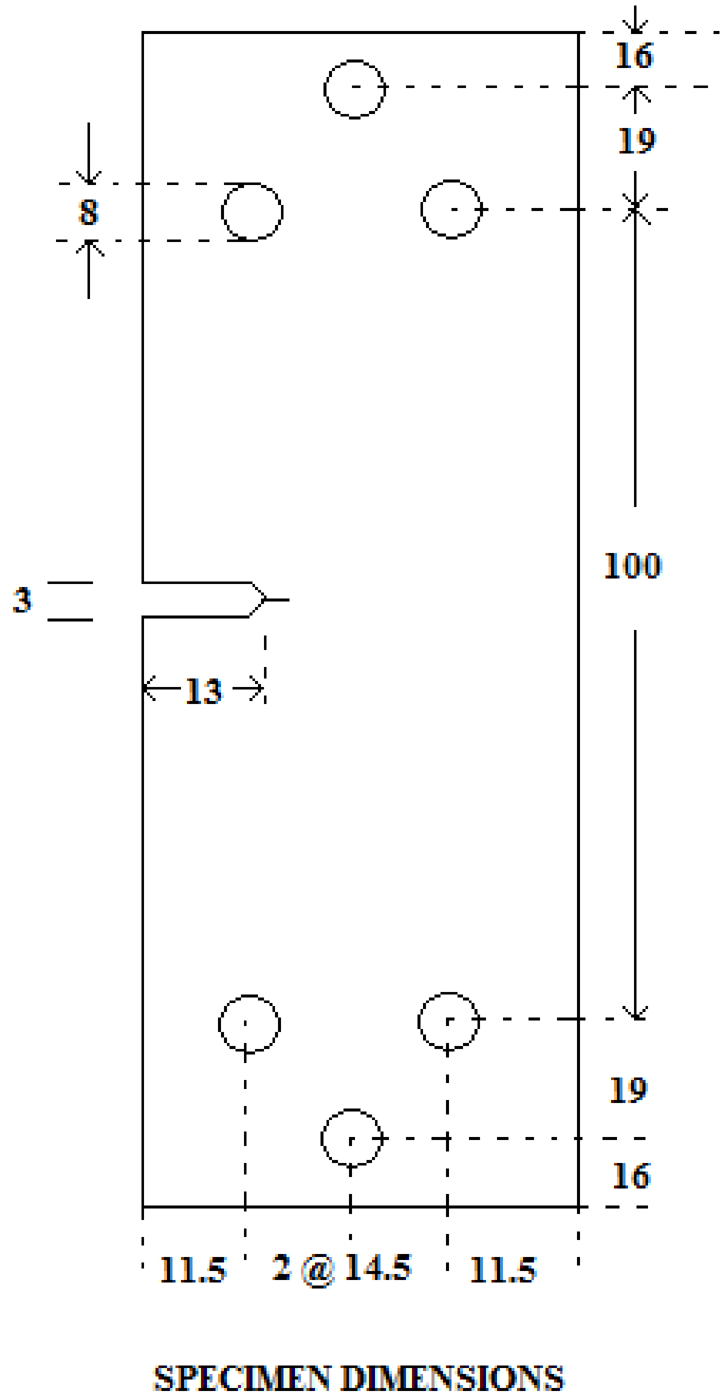

Figure 3.1: Single Edge Notch Specimen

3.3 EXPERIMENTAL METHODOLOGY:

1. Precracking of the specimen was done upto an a/w ratio of 0.3 in the Mode I loading with a sinusoidal waveform using a Stress Ratio of 0.1.

   Initial Length=13.5 mm
   Final Precracking Length = 15.4 mm

2. Stress Intensity Factor, K was calculated using Brown and Strawley equations [17].

$$K = f(g).\frac{F\sqrt{\pi a}}{wB}$$

$$\text{where, } f(g) = 1.12 - 0.231(a/w) + 10.55(a/w)^2 - 21.72(a/w)^3 + 30.39(a/w)^4$$

…………………eqn 3.1

3. The fatigue crack is allowed to grow up to an a/w ratio of 0.4 at frequency of 6 hz and subsequently subjected to multiple overload cycle at a load rate of 8 KN/min.

4. The specimens are to be subjected to Mode I overload rates at different overload ratios: [16]

Specimen No.	Overload Ratio, R
1	1.9
2	1.9
3	1.9
4	1.9

$$R_{ol} = \frac{K_{ol}}{K^{B}_{max}}$$

………………......eqn 3.2

where, K^{B}_{max} is the maximum SIF for baseline test.

K_{ol} is the SIF at overload.
B is plate thickness.
F is remotely applied load.
$f(g)$ is geometric factor.

5. After application of the band overload, the specimens will be subjected to Mode I constant amplitude load cycle at a frequency of 10 hz.

4. RESULTS AND DISCUSSIONS:

SPECIMEN NO 1 : 100 overload cycles

No. of cycles	Crack Length	a/w	Delta K	da/dN
85000	20.3	0.393716059	9.97522464	0.000202429
89940	21.3	0.413110939	10.79802556	0.000387597
92520	22.3	0.432505818	11.66747668	0.000285714
96020	23.3	0.451900698	12.60030066	0.000454545
98220	24.3	0.471295578	13.60921058	0.000833333
99420	25.3	0.490690458	14.80496883	0.001
100420	26.3	0.510085337	16.03125555	0.001111111
101320	27.3	0.529480217	17.5118727	0.001515152
101980	28.3	0.548875097	19.25838181	0.002439024
102390	29.3	0.568269977	20.75863058	0.002325581
102820	30.3	0.587664856		

SPECIMEN NO. 2 : 10 overload cycles

No. of cycles	Crack Length	a/w	Delta K	da/dN
85000	20.3	0.393716059	9.97522464	0.00016889
90921	21.3	0.413110939	10.79802556	0.000160772
97141	22.3	0.432505818	11.66747668	0.000263158
100941	23.3	0.451900698	12.60030066	0.000284091
104461	24.3	0.471295578	13.60921058	0.00034965
107321	25.3	0.490690458	14.80496883	

SPECIMEN NO 3: 5 overload cycle

No. of cycles	Crack Length	a/w	Delta K	da/dN
85000	20.3	0.387897595	9.90124173	0.000118624
93430	21.3	0.407292475	10.72171347	0.000166113
99450	22.3	0.426687355	11.58873015	0.000186567
104810	23.3	0.446082234	12.51892004	0.000303951
108100	24.3	0.465477114	13.52494221	0.000319489
111230	25.3	0.484871994	14.71693057	0.000358423
114020	26.3	0.504266874	15.9395603	0.000613497
115650	27.3	0.523661753	17.41538782	0.000571429
117400	28.3	0.543056633	19.15603362	0.001256281
118196	29.3	0.562451513	20.65208429	0.000518135
120126	30.3	0.581846393	22.77027451	

SPECIMEN NO 4: Baseline (No Overload)

No. of cycles	Crack Length	a/w	Delta K	da/dN
85000	20.3	0.393716059	9.97522464	0.000273748
88653	21.3	0.413110939	10.79802556	0.000326052
91720	22.3	0.432505818	11.66747668	0.000441891
93983	23.3	0.451900698	12.60030066	0.000559284
95771	24.3	0.471295578	13.60921058	0.000671592
97270	25.3	0.490690458	14.80496883	0.00092081
98346	26.3	0.510085337	16.03125555	0.001172333
99199	27.3	0.529480217	17.5118727	0.001410437
99908	28.3	0.548875097	19.25838181	0.001915709
100430	29.3	0.568269977	20.75863058	0.002272727
100870	30.3	0.587664856		

PLOTS AND GRAPHS:

4.1 SPECIMEN NO. 1: 100 OVERLOAD CYCLES

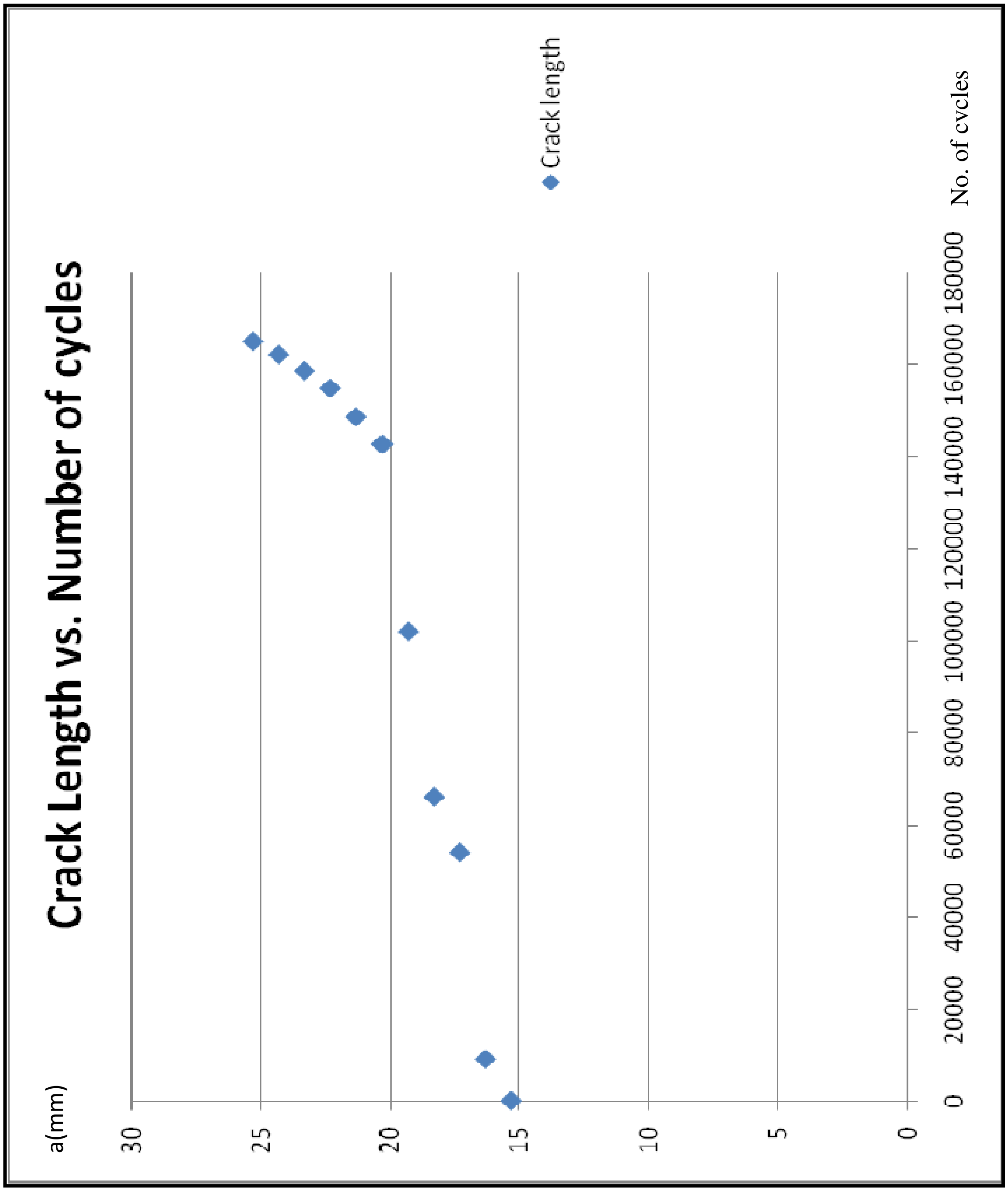

Figure 4.1 : Plots of crack length vs. Number of cycles for 100 overload cycles

4.2 SPECIMEN NO. 2: 10 OVERLOAD CYCLES

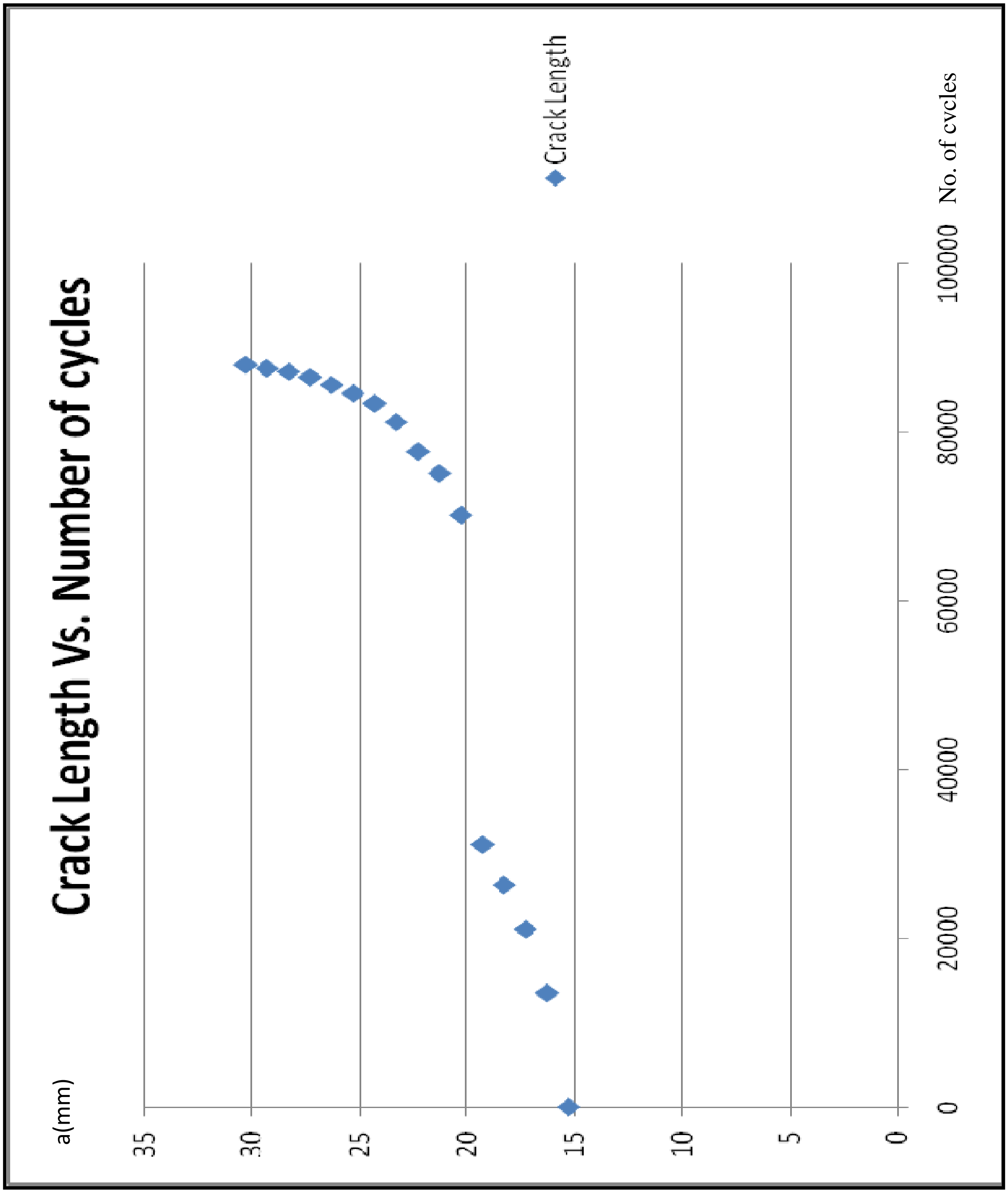

Figure 4.2 : Plots of crack length vs. Number of cycles for 10 overload cycles

4.3 SPECIMEN NO. 3: 5 OVERLOAD CYCLES

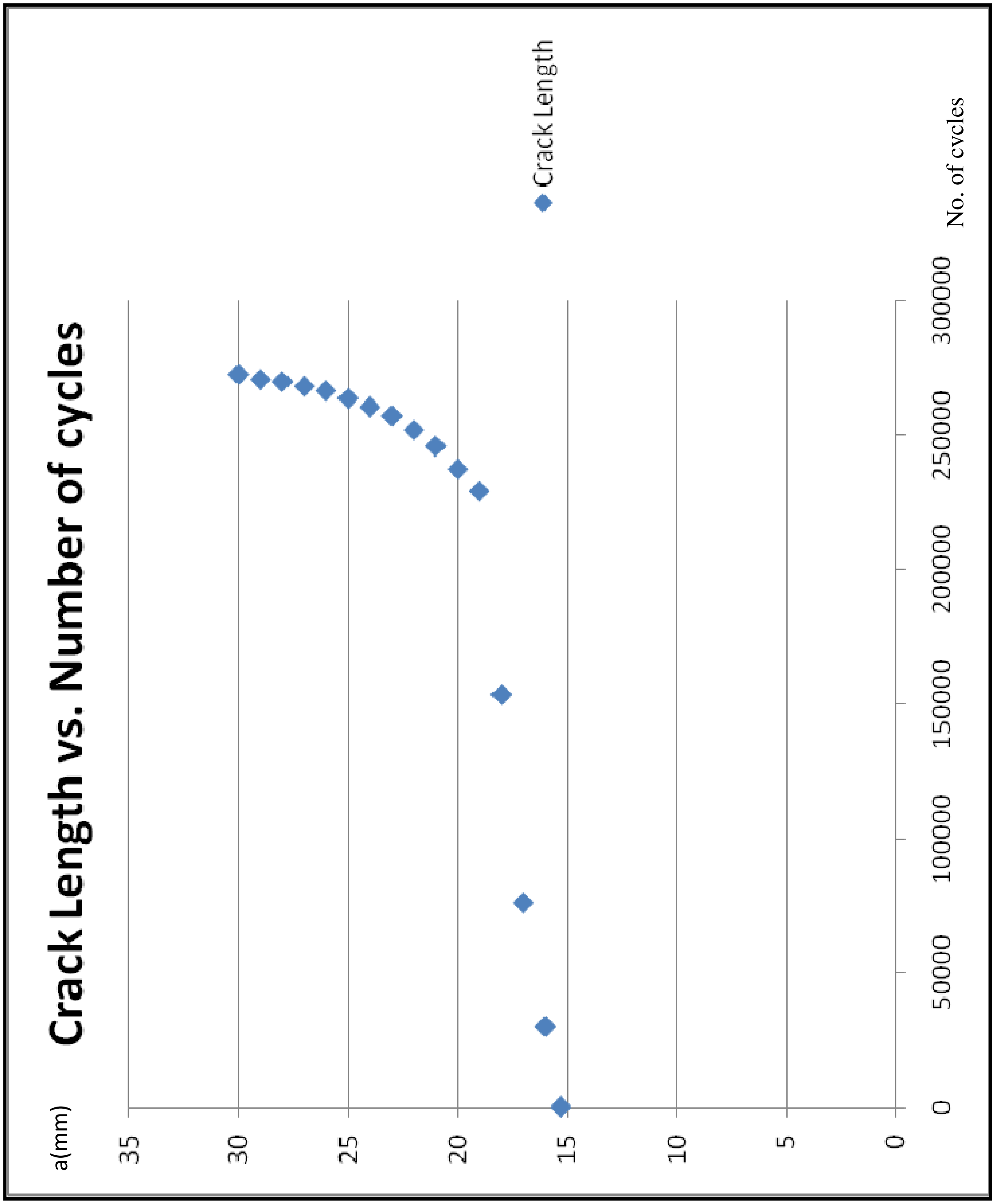

Figure 4.3 : Plots of crack length vs. Number of cycles for 5 overload cycles

4.4 SPECIMEN NO. 4: BASELINE - LOADING (NO OVERLOAD)

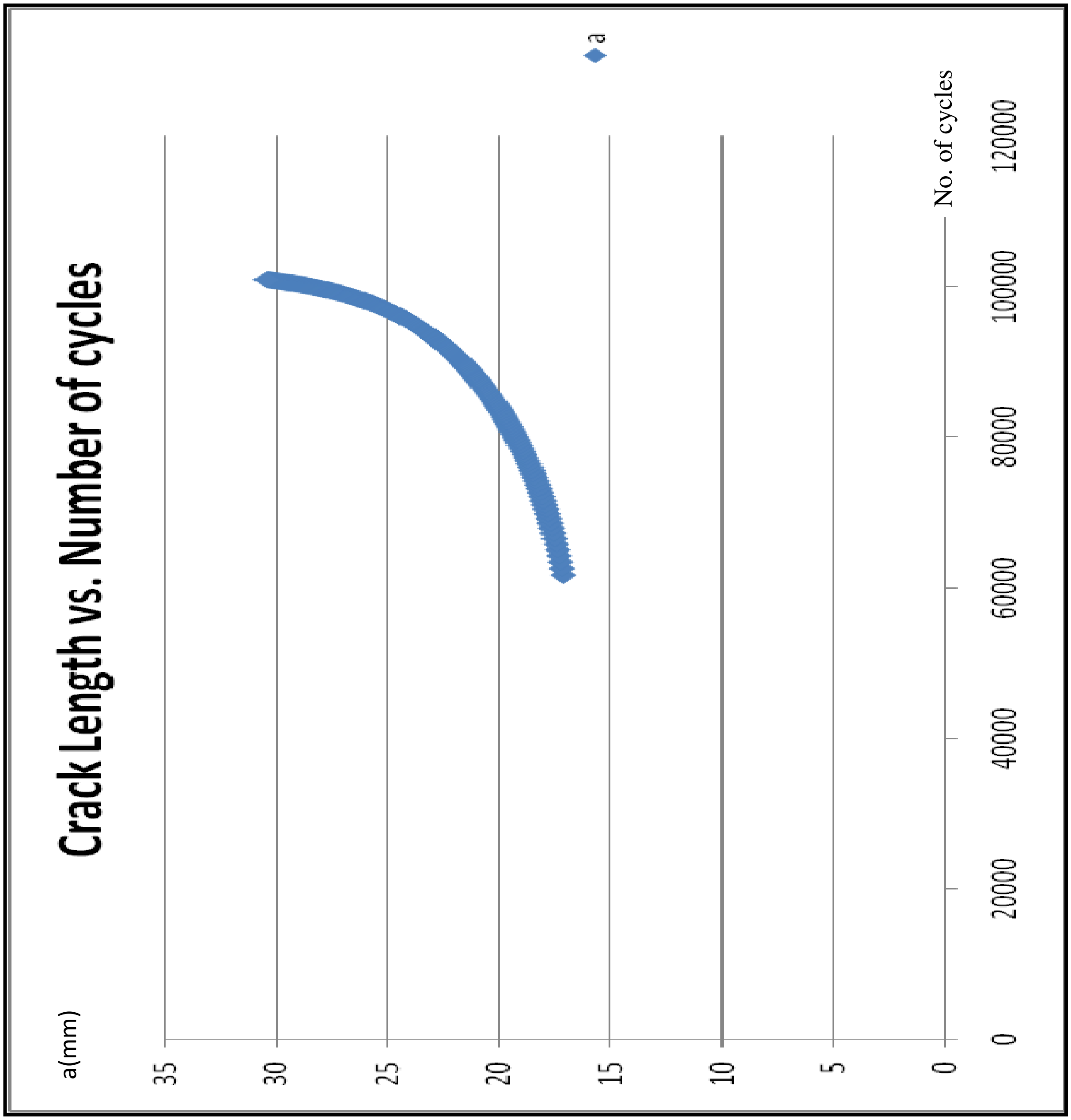

Figure 4.4 : Plots of crack length vs. Number of cycles for Baseline loading.

4.5 COMBINED CRACK LENGTH VS. NO. OF CYCLES PLOTS :

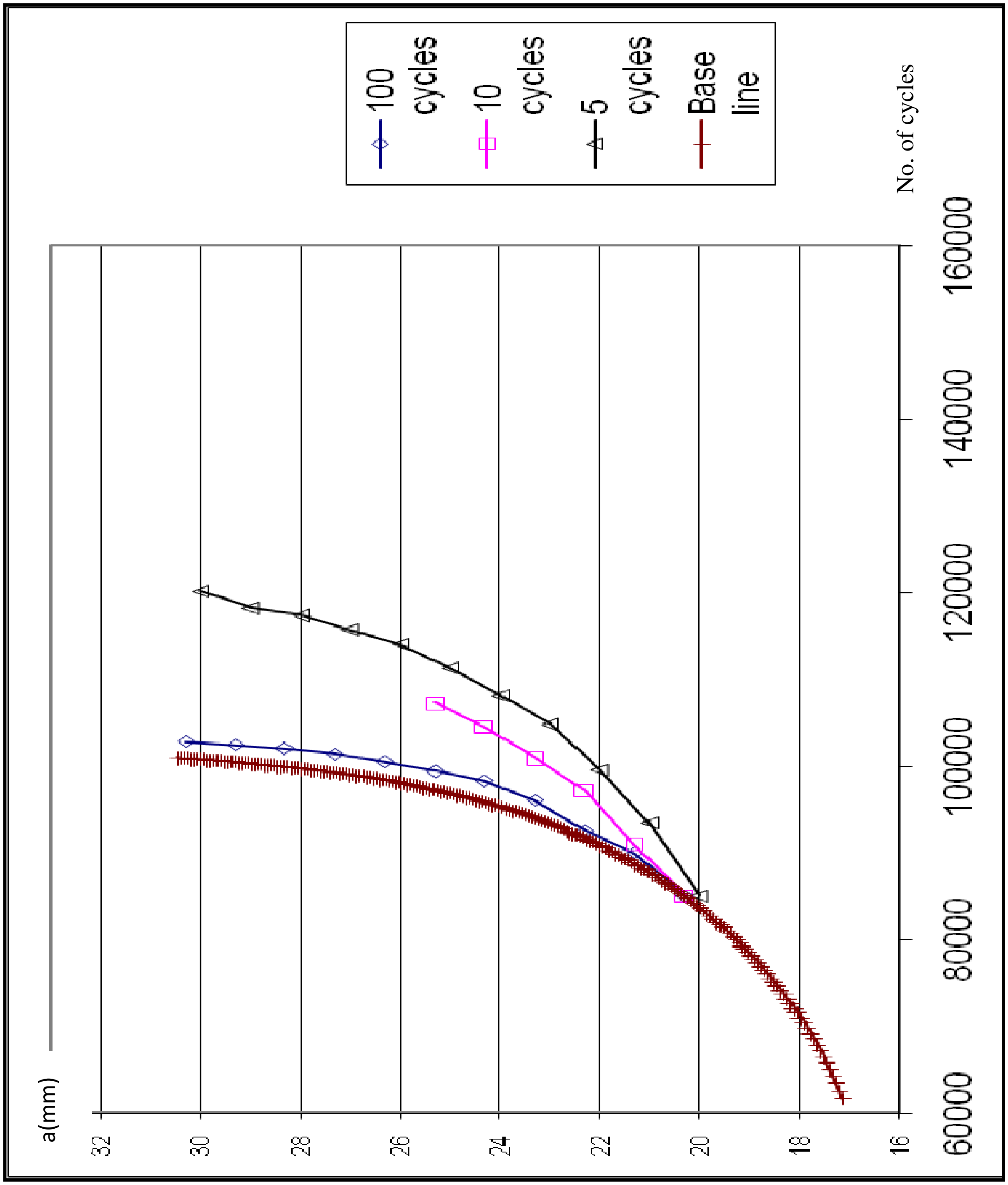

Figure 4.5 : Plots of crack length vs. Number of cycles for (Overlapped)

4.6. SPECIMEN NO 1: 100 OVERLOAD CYCLE

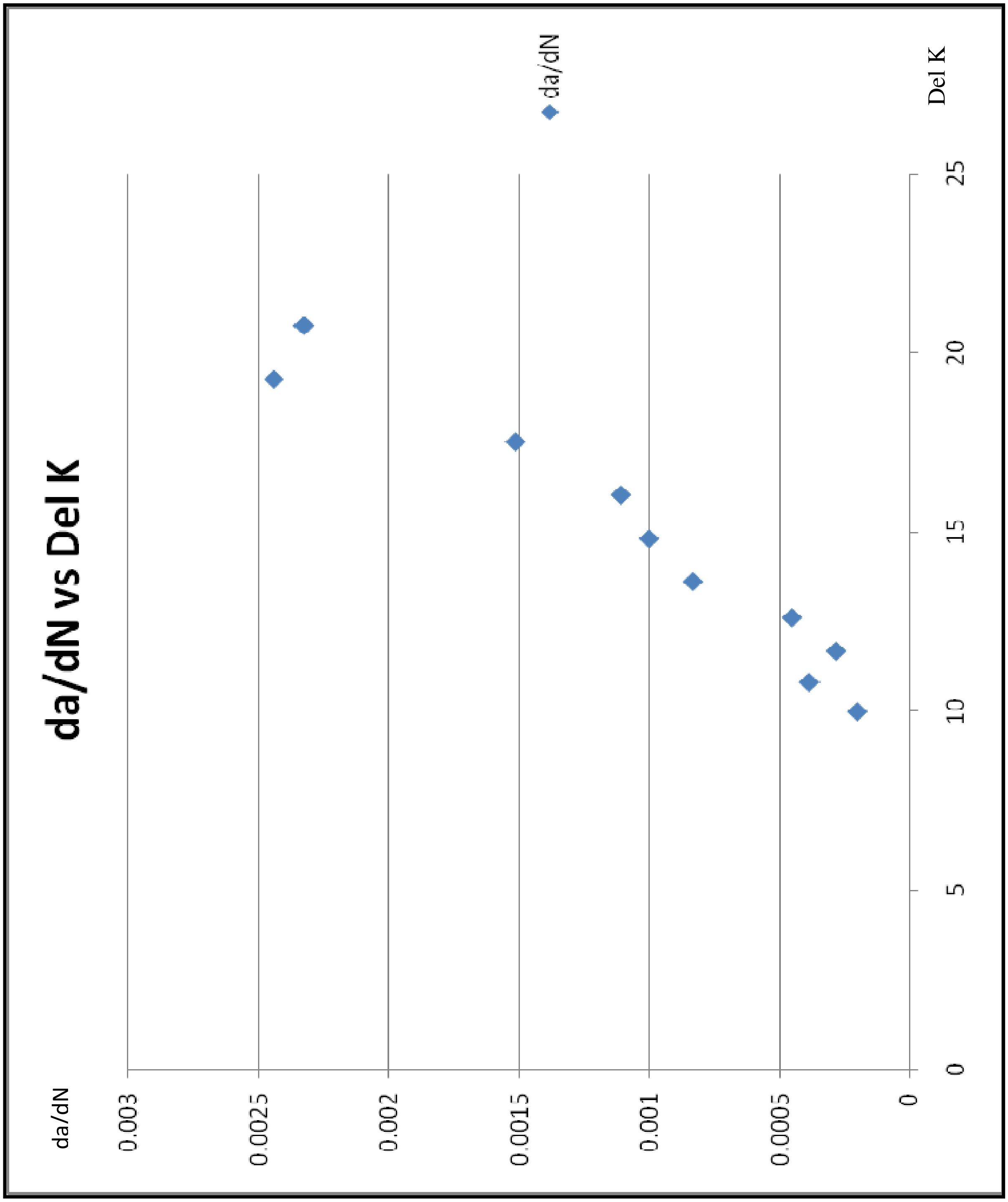

Figure 4.6 : Plots of da/dN vs. Del K for 100 overload cycles

4.7. SPECIMEN NO 2: 10 OVERLOAD CYCLE

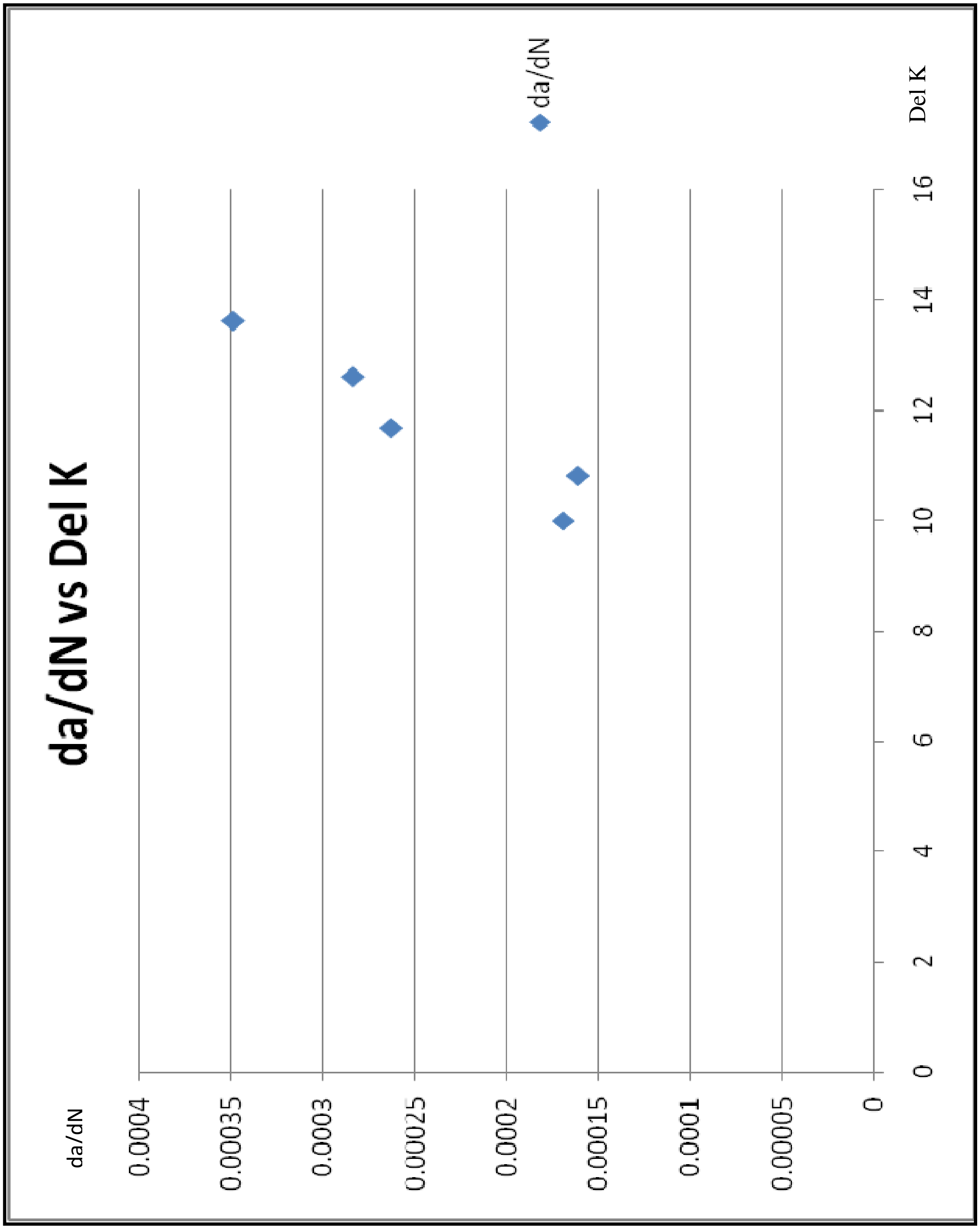

Figure 4.7 : Plots of da/dN vs. Del K for 10 overload cycles

4.8. SPECIMEN NO 3: 5 OVERLOAD CYCLE

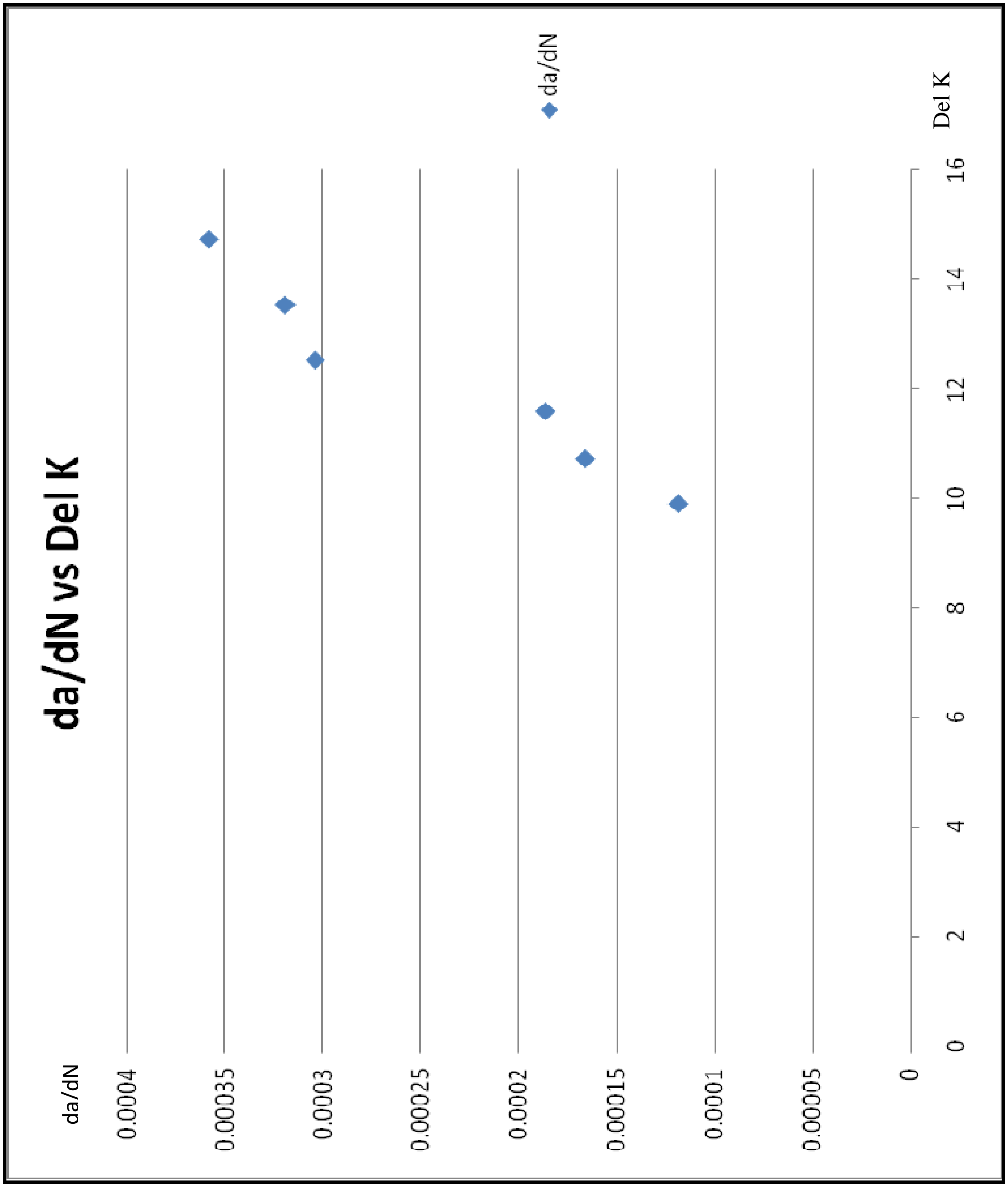

Figure 4.8 : Plots of da/dN vs. Del K for 5 overload cycles

4.9. SPECIMEN NO 4: BASELINE-LOADING (NO OVERLOAD)

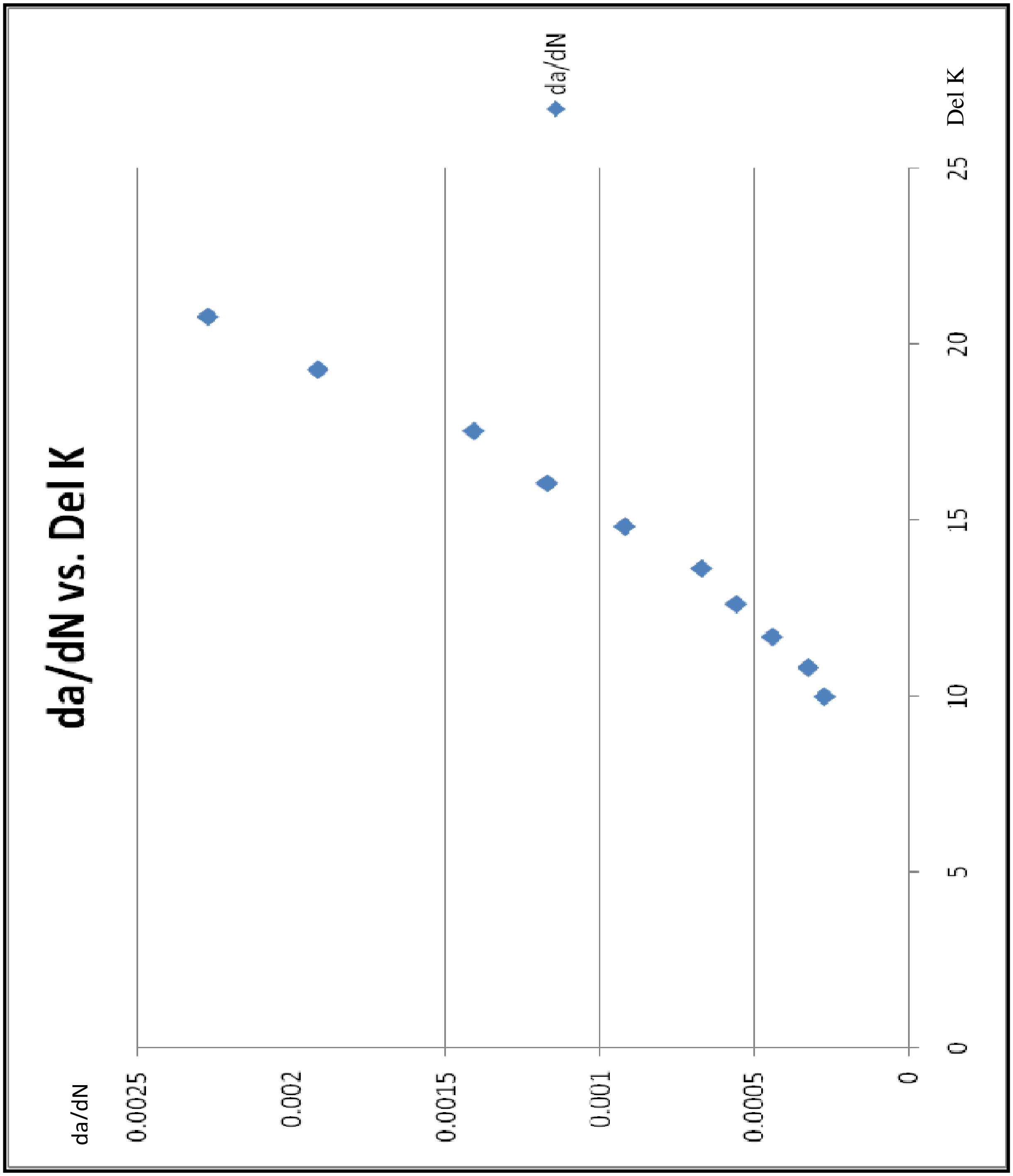

Figure 4.9 : Plots of da/dN vs. Del K for Baseline loading

4.10 COMBINED da/dN vs DeltaK PLOTS :

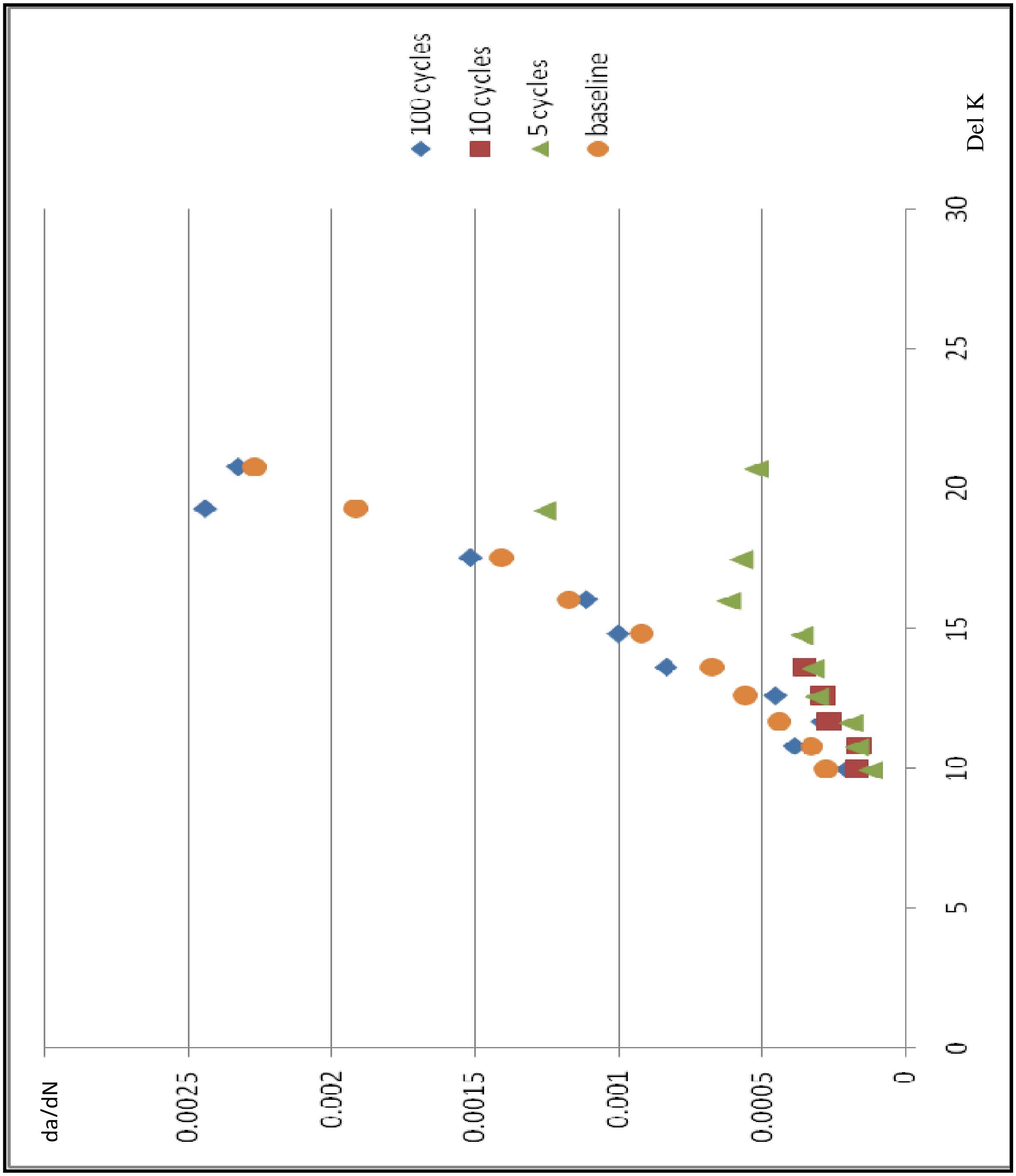

Figure 4.10 : Plots of crack length vs. Number of cycles for da/dN vs Del K (Overlapped)

DISCUSSIONS:

The four specimens were tested on INSTRON 8502 and the above results were obtained and duly recorded. The overload cycles were applied at an a/w of 0.4. The amplitude and frequency for normal loading were 3.2 MPa and 6 Hz respectively, while those at overloading cycles were 6.4 MPa and 10 Hz respectively. The readings were then plotted and compared against baseline graph (without overload). It was observed that the multiple overloads helped in crack growth retardation somehow. Though when compared with previous data available for single overload, it shows that single overload retards the crack to the maximum. More the number of cycles of overload, less is the crack growth retardation in case of Aluminum 2024 T3 alloy. Further, the da/dN vs ΔK curves were being plot for all the specimens.

5. CONCLUSIONS:

The following conclusions can be drawn from the experiment and its results:

1. During the Mode I normal loading, the crack first grows a little slow after that it increases rapidly as Del K has increased considerably verifying the crack growth rate as an exponential function of Del K.

2. The retardation is maximum for single spike overloads and least for 100 overload cycles. Hence, more the no of overload cycles lesser is its effect on retarding the crack growth.

3. The effect of no. of overload cycles on fatigue crack growth retardation follows the following trend.

   1 cycle >5 cycles > 10 cycles > 100 cycles > no overload (baseline-loading)

4. The slope of the da/dN curve for 100 cycle overload is maximum, again confirming the fact that 100 cycle overload does the minimum retardation of crack growth rate.

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