The Effect of Residual Stress State in the Notch Root Region Caused by the Hold Period of the Overload to the Fatigue Life

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***Abstract*— In the present study, the effect of the overload together with the hold period of the overload to the fatigue life associating with the crack emerging from the notch root region is investigated because the region is vulnerable to the plastic deformation. The result of the study shows that the fatigue life is affected by the residual stress state in front of the notch root, and the state of the residual stress depends on the constant amplitude load condition following of the overload. The residual stress developing in the front of the notch root relates to the plastic strain in front of the notch root during the overload. Besides that, the hold period of the overload enhances the plastic strain developing in the front of the notch root. The higher plastic strain in front of the notch root reduces the compressive residual stress and increases the tensile residual stress. In addition, the compressive residual increases the fatigue life but the tensile one lowers the fatigue life. Therefore, the hold period of the overload may decrease the fatigue life.**

Keyword- Notch root, Residual stress, Overload, Hold period, Fatigue life

I. INTRODUCTION

The failure of components relating to the cyclic loads, mostly originate from the stress concentration site in the components because the stress in the site may cause plastic deformation, thus, in connection with cyclic loads the crack will initiate in the site [1], [2]. If the crack propagates to a certain length, and it is not detected, a component will be failure. The failure of a component endangers integrity of a structure. The stress concentration site is often impossible to be avoided in components of structures, and it can be in any kind of forms, such as holes for nut-bolt joint, diameter reduction, and notch. In addition, the stress concentration site also may be caused by defects relating to manufacture process [1], [2]. In accordance with that, it is important to understand the fatigue life of a component relating to the crack growth originating from the stress concentration site.

The number of cycles load required to the crack initiation may be greater than that required to the crack growth before a component to be failure. If so, this condition is called as crack initiation dominant. This means that the fatigue life of a component before failure is dominated to initiate the crack. In the other hand, it is called as crack growth dominant in which the number of cycles required to crack growth is greater in comparison to that for the initiation [1]. In association with the crack initiated from the stress concentration site, these dominations of fatigue life depend on the type of materials, cyclic loads condition and the residual stress condition [1],[2].

It is well known that the compressive residual stress in front of the crack tip can retard a crack growth, and the fatigue life becomes longer [3]-[8]. In the case of crack originating from the stress concentration site, such as a hole, to enhance the fatigue life, the compressive residual stress is introduced in the edge of hole by expanding the hole [9], [10]. However, the stress concentration not only in the form of hole, but also may be in other forms, i.e., notch. In the previous investigation shows that the crack growth behaviour emanating from the notch root is strongly influenced by residual stress conditions developing in front of the notch root, and the residual stress condition depends on the cyclic load conditions after overloading [11]. If the cyclic load is initiated with the overload, which is higher than the following amplitude load, and the stress ratio of the following amplitude load is zero, the compressive residual stress develops in the region in front of the notch root. This leads to the retardation of crack growth and the increase of fatigue life. In the other hand, the tensile residual stress develops in front of the notch root if the following amplitude load is under negative stress ratio. In this case, the fatigue life decreases. The residual stress develops in front of the notch root has an association with the plastic deformation of the element material in front of the notch root. The magnitude and the state of the residual stress depend on the level of the overload and the amplitude load condition following the overload [11].

In service most of components have to carry variable amplitude load rather than constant load [1], [2], and it is very possible that a component may be loaded under those kind of loads. In addition, the component may be loaded in long periods. In association with the long period load together with elevated temperature, although the load is below the strength of material, the plastic deformation may take place. This phenomenon is well known as creep. However, the creep may be observed in room temperature, and even it may take place in a high strength metal [12]-[14]. Because the region near by the stress concentration is vulnerable to the plastic deformation which associates with the development of the residual stress, and this will affect the life time of a component, especially when it is cycled under variable amplitude load, therefore the effect of residual stress in front of the notch root caused by the overload in connection with the hold period of the overload to the fatigue life, in the present study, is investigated.

II. METHOD OF THE STUDY

To know to the fatigue life of a notch member in association with the variable amplitude load and the period of hold of the overload, the commercial aluminium was selected as the material of specimens, and the mechanical properties of the material are 110 and 215 MPa. for yield strength and ultimate tensile strength, respectively, and the elongation is 48 %. Fig. 1 shows schematically the shape of specimen, and its dimension is 220, 40 and 3 mm, respectively, for length, width and thickness. The single sharp notch with 0.3 mm of notch root diameter and 5 mm in length was cut on the edge of mid-section of the specimen. The fatigue life, Nr, was determined by counting the number of the cycles required the crack grows in the region affected by the overload deformed plastically, and it is found that the maximum of the region to be 0.8 mm from the notch root in the present. Because of that, the traveling digital microscope with accuracy 10 μm was employed to observe the growth of crack originating from the notch root, and in order the crack growth to be observable, the surface of specimen was polished with an emery paper and a paste of metal polish to obtain a mirror like surface.

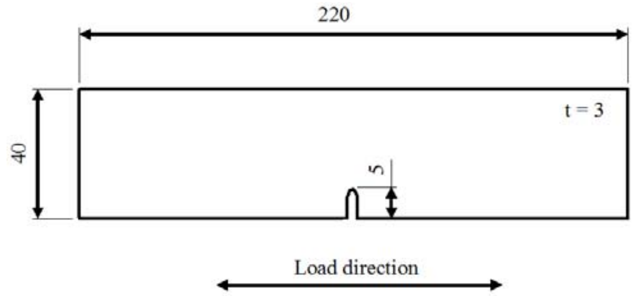
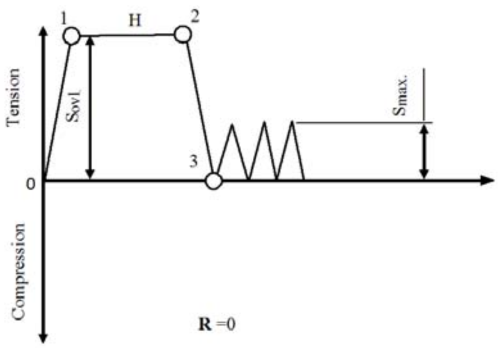
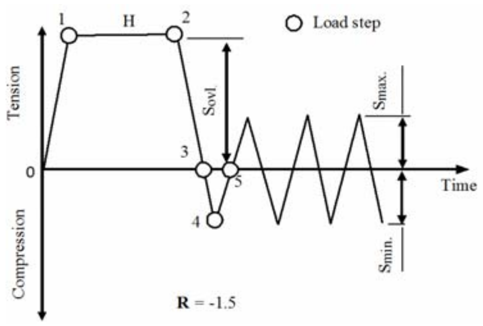


Fig. 1. The shape of the specimen

The test was conducted in the laboratory at room temperature condition by a servo-hydraulic push–pull testing machine, and the frequency of the constant amplitude load was 10 Hz, and the example load condition subjected to the specimens is depicted schematically in Fig.2 in which it represents of cyclic load pattern when the stress ratio of the constant amplitude load, R, is 0 and -1.5. The stress ratio is defined as the ratio of minimum stress, S_{min}., to maximum stress, S_{max}., of constant amplitude load, and $S_{ovl.}$ is the overload stress. Before being cycled under constant amplitude load, the specimens were overloaded and held in some periods of time, H. Table 1 shows the testing condition. The specimens which are not be overloaded are defined as the base, and to know the effect of the hold periods of the overload to the fatigue life, the test was carried out also to the specimens without being held in the overloading to be compared to the specimens with the hold period of the overload.



(a).



(b).

Fig. 2. The representation of cycle's pattern

Because the crack initiation in the notch root associates with the residual stress condition developing in front of the notch root [11], and it will affect the fatigue life, thus, the development of the residual stress was investigated by simulating the load as represented in the Fig.2 in the computer. The computer simulation was conducted by aid of ANSYS code. Due to symmetry, to simulate the loading condition to the specimens, the semi-model was used in the present simulation, and the meshing is shown in this manner as shown in the Fig.3. In this simulation, because the stress state in front of the notch root depends on the loading condition after overloading, the stress analysis was focused on every load step as indicated in the Fig.2. The load step 1 is the overload, and the load step 2 is the step after the overload was held in the period of time, H. After being held, the load is returned to the zero load in the load step 3 when the stress ratio of constant amplitude load is zero. When the stress ratio is -1.5, the load is continued to compressive load in the load step 4, and then the load is returned to the zero load in the load step 5.

TABLE I. Testing Conditions

<table>
<tr><th>No.</th><th>R</th><th>$S_{max.}$ (MPa.)</th><th>$S_{ovl.}$ (MPa.)</th><th>H (minutes)</th></tr>
<tr><td>1</td><td rowspan="7">0</td><td rowspan="7">30</td><td>-</td><td rowspan="4">0</td></tr>
<tr><td>2</td><td>40</td></tr>
<tr><td>3</td><td>60</td></tr>
<tr><td>4</td><td>86</td></tr>
<tr><td>5</td><td>40</td><td rowspan="3">45</td></tr>
<tr><td>6</td><td>60</td></tr>
<tr><td>7</td><td>86</td></tr>
<tr><td>8</td><td rowspan="7">-1.5</td><td rowspan="7">25</td><td>-</td><td rowspan="4">0</td></tr>
<tr><td>9</td><td>40</td></tr>
<tr><td>10</td><td>60</td></tr>
<tr><td>11</td><td>86</td></tr>
<tr><td>12</td><td>40</td><td rowspan="3">45</td></tr>
<tr><td>13</td><td>60</td></tr>
<tr><td>14</td><td>86</td></tr>
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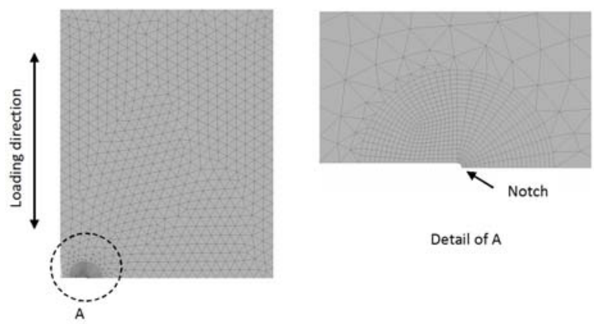
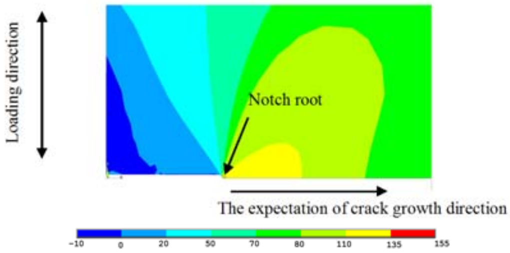


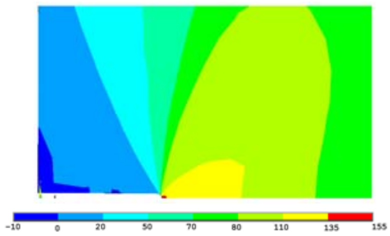
Fig. 3. The semi-model and meshing of the specimen

III. Results of the Study

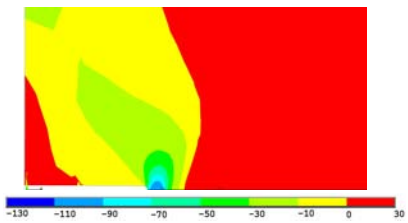
Fig. 4 shows an example of the stress contour being parallel to the load direction in the region near by the notch root for every load step as indicated in Fig. 2 in the case of stress ratio -1.5, 60 MPa. of overload and 45 minutes of the holding period of the overload. The stress direction being parallel to the loading direction only is considered because it is common that the crack grows perpendicular to the principal stress [11], [15], and in the present study the principal stress is parallel to the loading direction as indicated in the Fig. 4. In the load step 1 or in the overload point, the stress concentrates in the region in front of the notch root as pointed by the arrow, and after being held for 45 minutes in the overload level or load step 2, the stress concentrated in the region in front of the notch root is higher in comparison to the overload point as indicated by the red colour. After being held in the overload level, the load is returned to zero load of load step 3. In this step although the load is zero, there is stress concentration region in front of the notch root as indicated by the light blue colour. It is an indication that the compressive residual stress developing in that region. If the load step is continued to the load step 4, which is the minimum load of the constant amplitude load, the light blue colour region becomes to the dark blue and wider. This indicates that that region is in higher compressive stress than the previous step. As the load is returned to the zero load of load step 5, the light yellow and cyan colours appear just in front of the notch root, and it indicates that the tensile residual stress develops in that region. The residual stress state developing in the load step 5 will affect the crack growth behaviour after overloading when it is continued to be cycled under the constant amplitude load [3]-[8], [11], [14].



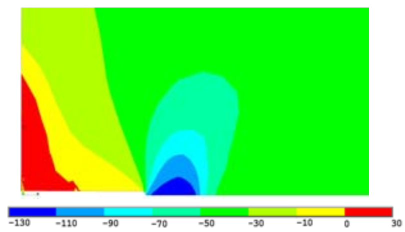
Load step 1



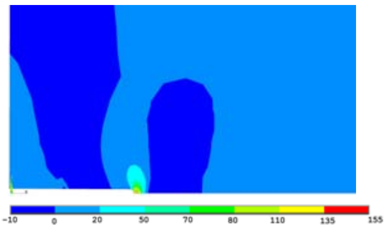
Load step 2



Load step 3



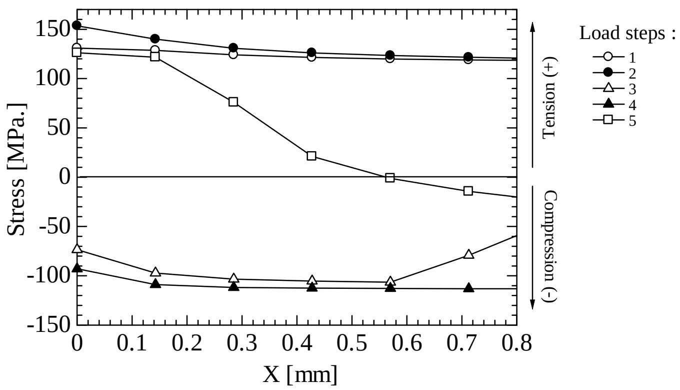
Load step 4



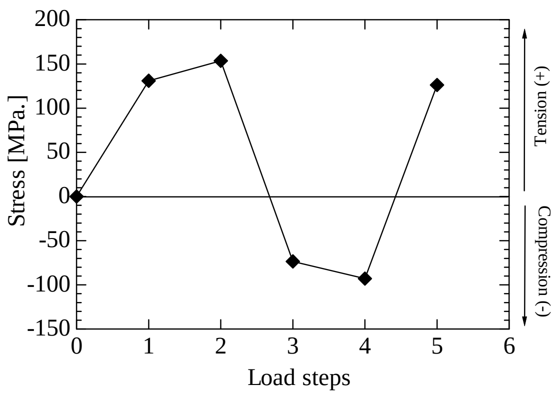
Load step 5

Fig. 4. The stress contour on the specimen with R = -1.5, 60 MPa. of overload and H = 45 minutes

The stress state and the change of its magnitude in front of the notch root as depicted in the Fig. 4 is summarized in the Fig. 5 for every load step. The distance from the notch root is denoted as X. With respect to the Fig. 5(a) showing the variation and stress state in front of the notch root, it can be observed that after being held for 45 minutes in the overload level, load step 2, the stress in the notch root is higher than that in the load step 1, and the stress returns gradually to the stress level as high as the overload level, load step 1, when the distance from the notch root is increase. The compressive residual stress develops in the load step 3 in which the load is zero, and after being continued to the minimum load of constant amplitude load, load step 4, the stress in the region in front of the notch root is in compressive state. The tensile residual stress develops in the load step 5 after the load is returned to the zero load from the minimum load of load step 4, and the magnitude of the residual tensile strength decreases as the effect of the overload to be not profound. The Fig. 5(b) shows the magnitude of stress and its state in every load step occurring in the notch root. Because the residual stress state developing in front the notch root after the overload affects the fatigue life and the crack growth behaviour [11], hereafter, the residual stress state in the load step 3 and load step 5 for stress ratio 0 and -1.5, respectively will be considered in the present study.



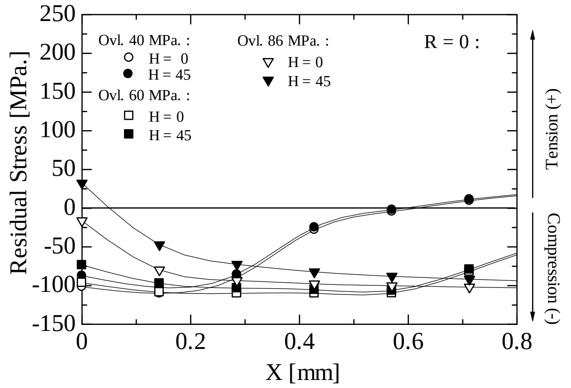
(a).



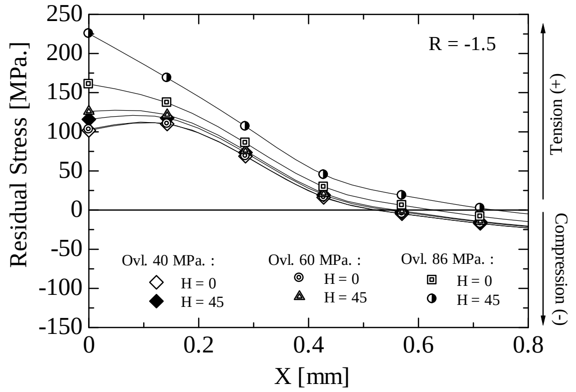
(b).

Fig. 5. Summary of stress distribution in front of the notch on the specimen with R = -1.5, 60 MPa. of overload and H = 45 minutes

Fig. 6 shows the distribution of the residual stress after being overloaded with and without holding period for stress ratio 0 and -1.5, respectively. In the case of stress ratio 0, the compressive residual stress develops in front of the notch root, and depending on the magnitude of the overload and the hold period, it varies to the distance from the notch root. From the figure, it can be seen that the hold period reduces the magnitude of the compressive residual stress. Even, when the overload is as high as 86 MPa. and held, just in the notch root the state of the residual stress is tensile. In the case of the magnitude of the overload is 40 and 60 MPa., the effect of the holding period is less pronounced in comparison to the 86 MPa. of the overload. The different in this case is only in the short range of the compressive residual stress region in front of the notch root. When the overload is 40 MPa., the compressive residual stress is slightly higher than that of 60 MPa. just in front of the notch root, however, the range is shorter than in 60 MPa. of overload before the compressive residual stress gradually diminish. In other hand, in the case of stress ratio is -1.5, the tensile residual stress instead of the compressive one develops in front of the notch root, and as the same as in the case of stress ratio is 0, the hold period of the overload affects the magnitude of the residual stress. Its effect is profound when the overload level is as high as 86 MPa. in which the tensile residual stress is higher than that without hold period.



(a).



(b).

Fig. 6. The effect of the held overload to the residual stress in the region in front of the notch root.

It is well known that the number of cycles required initiating a crack before growing associates with the residual stress state in the region in which the crack initiation takes places [11]. In this respect, the Fig. 7 shows the residual stress state in the notch root where X equals to zero for stress ratio 0 and -1.5, respectively. The continue line and the dash line represent expectation line for overload without and with hold period. The figure shows that the increasing of the overload reduces the compressive residual when the stress ratio is 0, and the hold period decreases the compressive residual stress, even the 86 MPa. of the overload, the hold period alters the state of the residual stress from compressive to tensile. The increasing of the magnitude of the overload increases the tensile residual stress in the notch root, and the hold period of the overload enhances the tensile residual stress developing in the notch root when the stress ratio is -1.5.

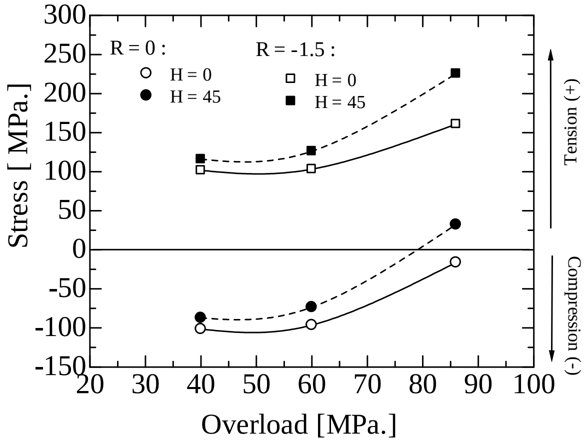
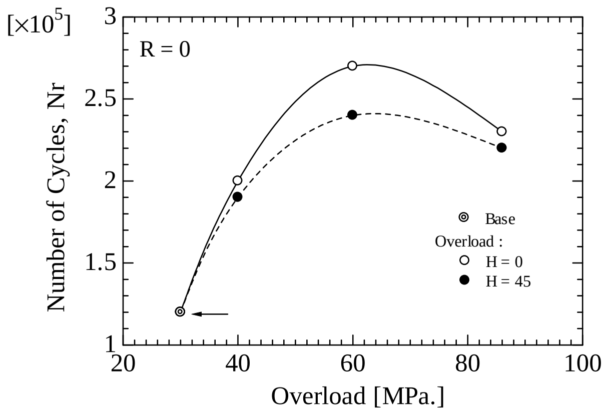
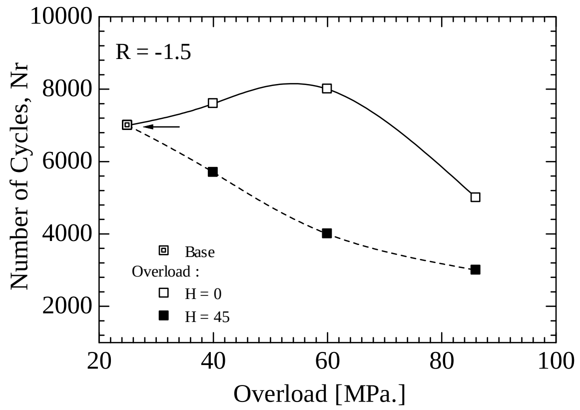


Fig. 7. The effect of the overload and the hold period to the residual stress in the notch root.

Because the state of the residual stress in the front of the notch root depending on the stress ratio of constant amplitude load affects the fatigue life, in the present study, hence, the effect was tested by cycling the specimens under the constant amplitude load following to the overload. The result of the test is shown in the Fig. 8 for stress ratio 0 and -1.5, respectively. The arrow points the fatigue life for the base. The continue and dash line represent the expectation line for each stress ratio. The result shows that the hold period of the overload reduces the fatigue life although the fatigue life is still longer than the base when the stress ratio is 0. However, when the constant amplitude load is cycled under stress ratio -1.5 following the overload with hold period, the fatigue life is shorter than that of the base in all levels of overload. This kind of condition will endanger a member of a structure because the fatigue life is shortened. Therefore, the hold period of the overload should be taken into consideration to estimate the fatigue life associating with the crack growth especially when the stress ratio of cyclic load is negative.



(a).



(b).

Fig. 8. The Relation of the number of cycles, Nr and the overload.

The results of the present study demonstrate that the hold period of the overload leads to the decreasing of the fatigue life although it is still higher than that of the base when the stress ratio zero. However, when the stress ratio is -1.5, the hold period of the overload causes the fatigue life to decrease being lower than that of the base in all levels of the overload, and it does not take place in the case of the overload without the hold period. In this case, the fatigue life is higher than that of the base for some levels of the overloads. The increasing and decreasing of the fatigue life corresponds to the residual stress state developing in front of the notch after being cycled to the constant amplitude load. The hold period of the overload lowers the compressive residual stress and enhances the tensile residual stress when stress ratio is 0 and -1.5, respectively.

IV. DISCUSSIONS

It has been known that the development of the residual stress related to the overload in front of the notch root or crack tip associates with the plastic deformation in the affected overload region [3]-[5], [11], [14]. The result of the study shows that the overload held in certain period influences the residual stress, and as consequently, it affects the fatigue life. Because of those, the plastic deformation developing during the overload held in the certain period was investigated. Fig. 9 shows the notch root conditions on specimen with 86 MPa. of the overload. The Fig. 9(a) is the notch before being overload, and the Fig.9(b) is the notch at the point of the overload (load step 1). The two black continue lines represent the wide of the notch root before being overloaded, and the white dash line represents the displacement of the upper surface of the notch in the overload point. The Fig. 9(c) to 9(e), respectively, show the slightly gradual displacement after being held in the overload for 15, 30 and 45 minutes, and the increasing displacement is indicated by the upper side of the notch being above of the white dash line. Finally, Fig. 9(f) shows the notch root condition after being cycled in constant amplitude load with stress ratio 0 for 1000 cycles. The upper side of the notch root is in the position between the black continue line and the white dash line. Because the upper side of the notch root does not return to the position as before the overload, this is an indication that the plastic deformation take places in front of the notch root. In addition, some cracks initiated from the notch root can be seen in the Fig. 9(f) but after some distances not all crack can grow. It relates to the residual stress state developing in in front of the notch root in which in this case, the residual stress state is compressive. The Fig. 10 shows better image related to it.

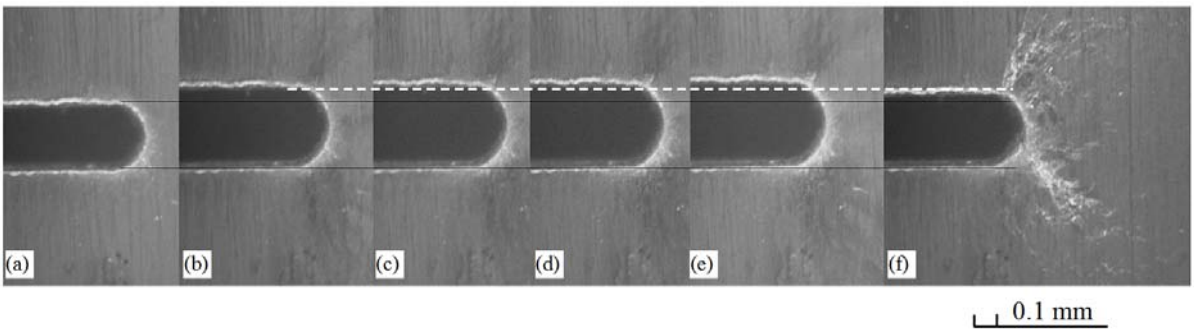


Fig. 9. The notch root condition of 86 MPa. overload, 45 minutes hold period and R = 0: a. Just before being overloaded, b. H=0, c. H=15, d. H=30, e. H=45 minutes, f. After being cycled for 1000 cycles.

The notch root condition after being cycled under constant amplitude load with stress ratio 0 following the overload with hold period is shown in the Fig.10 in which there are three main cracks initiated from the upper, middle and lower sites of the notch root. From the figure can be observed that the crack on the upper side of the notch root grew in the short distance only although the number of cycles of the constant amplitude load elapsed in 260,000 cycles. However, in the lower site of the notch root the crack advanced as the number of cycles increases. The different behaviour of the crack growth in the upper and lower site of the notch root associates probably with the crack initiation process. In this case, the lower side precedes the upper site, and then because of size of the crack, which is higher stress concentration in the longer one, hence the lower site crack grows continually as increasing of the number of cycles [5], [11], [14]. Because the compressive residual stress developed in front of the notch root, after reaching in short distance from the notch root the crack growth retarded as indicated by the crack growing from the middle site of the notch root. The length of this crack remained constant although the number of cycles had reached to the number of cycles in which the failure occurred. As in the Fig. 9, the white continue and dash line in the Fig.10 are used to indicate that the plastic deformation occurred in front of the notch root. As shown in the figure the position of the upper side surface of the notch remained the same from 20,000 to 260,000 cycles.

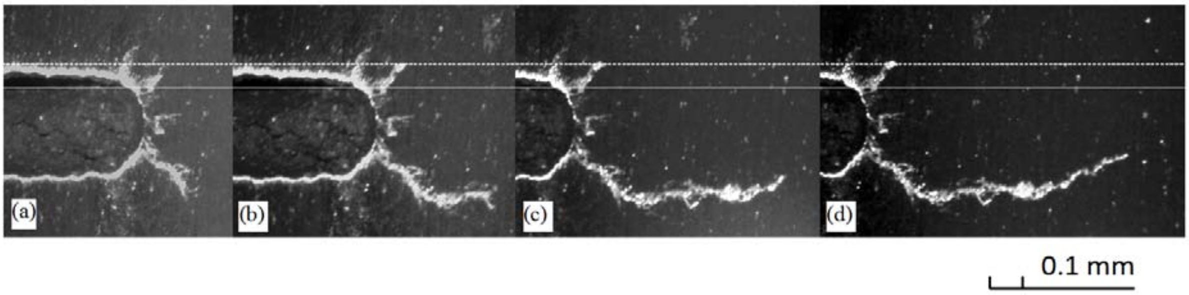
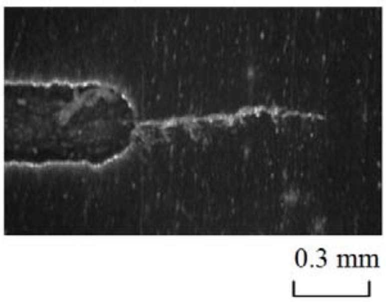


Fig. 10. The development of the crack growth in front of the notch root on the specimen with R =0, H = 45 minutes and 60 MPa. of overload : a. 20,000 cycles, b.60,000 cycles, c. 140,000 cycles, d. 260,000 cycles..

Figure 11 shows the crack growth after being cycled for 140,000 and 80,000 cycles in constant amplitude load, respectively, on the base specimen with R = 0 and on the specimen with R = -1.5 and being held during overload for 45 minutes. Both images show that the cracks emerge and grow straight ahead from the centre of the notch root. These are caused by stress state in front of the notch on which in the both cases, the compressive residual stresses do not develop in centre and in front of the notch root. These are indications that the cracks growth direction depending on the stress effectively advances the cracks. The tensile residual stress developing in the front of the notch root increases the stress effective, so the crack growth is accelerated, and consequently, the fatigue life is shortened [5], [11], [15]. Otherwise, if the compressive residual stress develops in front of the notch root, the effective stress decreases, and it leads to the deceleration of the crack growth, hence, the fatigue life is increased [11]. Those associate with the plastic deformation of the element material in front of the notch.



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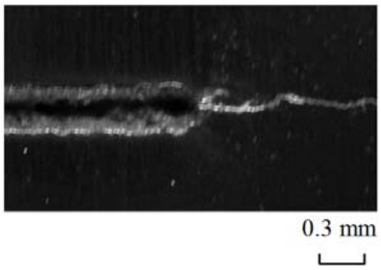
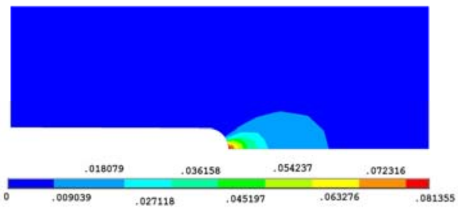


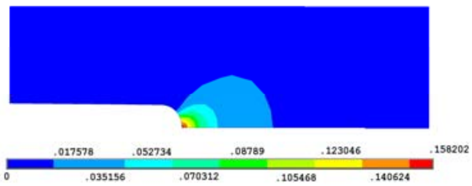
(b).

Fig. 11. The emerging of crack from the centre of the notch root: a. After 140,000 cycles for R = 0 base, b. After 80,000 cycles for R = -1.5 with 86 MPa.of overload and H = 45 minutes.

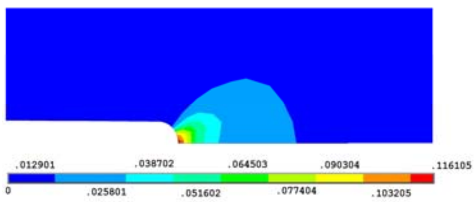
The development of the distribution of the plastic strain contour during overloading can be seen in the Fig. 12 for every load step. When the overload was applied or in load step 1, the plastic strain occurred in the region in front of the notch affected by the overload, and the plastic strain in the notch root is higher than elsewhere. The plastic deformation did not occur in the region when the effect of the overload is less pronounced. The plastic strain was increased by holding the overload for 45 minutes as shown in the figure of the load step 2. After being unloaded to zero loads from the overload, because the element material in front of the notch root deformed plastically, thus, the element material still stretched to the overload direction although the load is zero, and the deformation is still higher than that of the load step 1. It causes the compressive residual stress develops in the load step 3. The value of the plastic strain reach to the minimum value, when the load step is proceeded to the load step 4, which is minimum load of the constant amplitude load. Yet the element material plastically deformed still stretched to the overload direction, and this lead to the compressive stress in region in front of the notch root to be higher than other regions. As shown in the Fig. 5, the tensile residual stress develops in the very tiny region in front of the notch root in the load step 5. This tensile residual stress is caused by the increasing the plastic strain directing as the same as the overload direction when the load is returned from the load step 4 to the zero load of load step 5 on which its plastic strain is higher than that in the load step 4. The plastic strain distribution occurring from the notch root to the point under consideration in front of the crack notch is summarized in the Fig. 13.



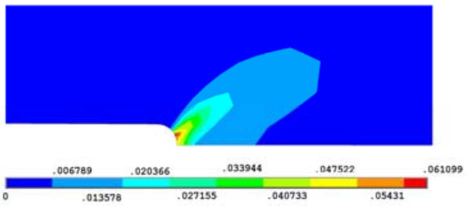
(a). Load step 1



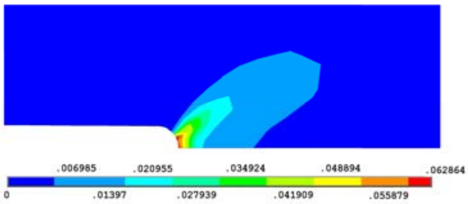
(b). Load step 2



(c). Load step 3



(d). Load step 4



(e). Load step 5

Fig. 12. The example of the development of plastic strain contour in front of the notch root, when R =-1.5, H = 45 minute and Overload = 60 MPa.

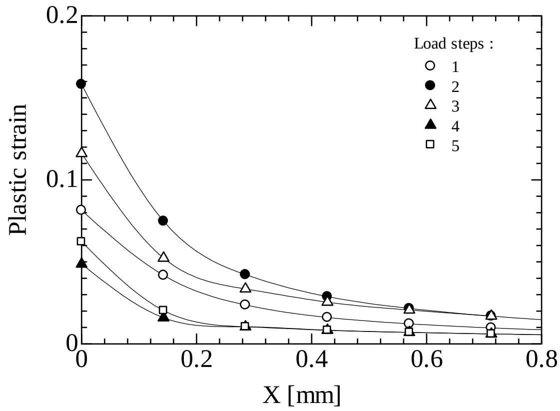


Fig. 13. The summary of the development of plastic strain in front of the notch root, when R =-1.5, H = 45 minutes and Overload = 60 MPa.

The relation of the plastic strain and the stress condition is explained in the Fig.14 in which the relation refers to the strain and stress in the notch root for specimen with 60 MPa. overload, 45 minutes hold period and R = -1.5. The dash line and continue line represent the hysteresis loop of strain-stress relation for overload without and with hold period, respectively, and the numbers indicate the load step. The 1-3-4-5 denotes the hysteresis loop for overload without hold period, and for the overload with hold period the loop is denoted as 1-2-3-4-5. When the overload was applied without hold period, the compressive residual stress develops after overloading as indicated by the number 3 of dash line. In this step, the plastic strain is lower than that developed in the load step 1, however, because the deformation is still in the overload direction, thus, the compressive residual stress develops in the step. The plastic deformation in load step 3 is lowered by proceeding to the compressive load of the constant amplitude load in the load step 4, and because the compressive load is high enough, the plastic strain is in reverse direction to the overload direction. After being returned to the zero load, which is load step 5, the plastic strain increases and being higher than takes place in the load step 4. Because this increase of plastic strain direction is in the same direction to the overload or in tension load, the tensile residual stress develops in this load step. The previous development of the plastic strain is similar to the development of the tensile residual stress in the case of overload with hold period, however, in this case, the plastic strain developing in the load step 1 is enhanced by the hold period, and it causes the plastic strain to be higher as indicated in the load step 2. Because of it, upon unloading to zero load or in the load step 3, the plastic strain remaining in the same direction to the overload is higher than that occurs in the previous case, as the result, the compressive stress in this step is lower also. In addition, the compressive load of the minimum load of the constant amplitude load does not enough to reverse the direction of the plastic strain, thus, the direction in the load step 4 remains as before. After being unloading to zero load (load step 5), the tensile residual stress develops because of the increase of plastic strain in the same direction to the overload, therefore, the residual state in in this step is tensile. The tensile residual stress is higher in comparison to the previous case. It is causes by the enhancement of the plastic strain during the hold period of the overload.

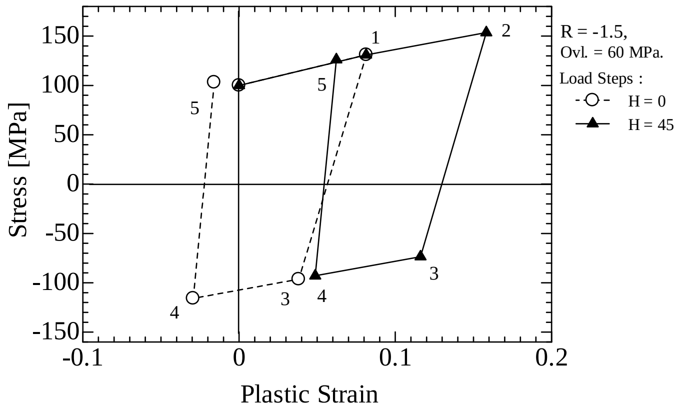
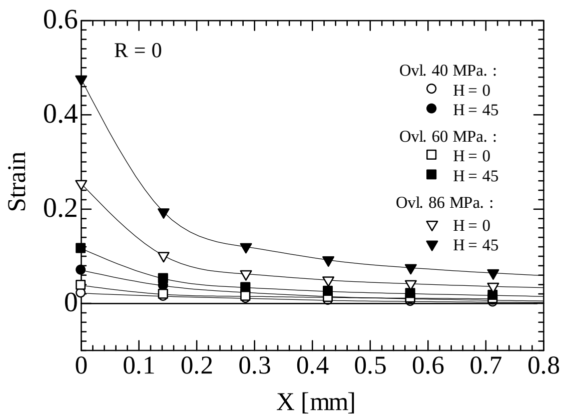
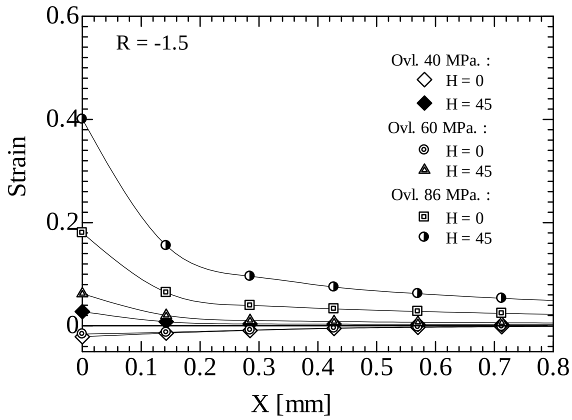


Fig. 14. The hysteresis loop of strain-stress relation

The Figure 14 demonstrates that the direction and the magnitude of the plastic strain developing in the load step 5 determines the residual stress state in front of the notch root. The higher plastic strain in that load step, the residual tensile stress developing is higher also when the stress ratio after overloading is -1.5. In the other hand when the stress ratio is 0, if the plastic strain caused by the overload is high enough in the load step 3, the tensile residual stress instead of the compressive residual stress tends to develop in front of the notch root. This is caused by the tensile stress associates to the notch root is high also during the overload, so upon unloading to zero load (load step 3), the tensile stress is still present although its magnitude decreases. It is the reason why the tensile residual stress also develops especially in region being very near to the notch root after being overloaded and held for 45 minute with stress ratio 0, and it reduces the fatigue life. Because the plastic strain after the overload is responsible to the fatigue life relating to the crack growth, it is important to know the effect of the overload and the hold period to the distribution of the plastic strain in front of the notch root. The Fig. 15 shows the plastic strain distribution in the load step 3 for stress ratio 0 and in the load step 5 for stress ratio -1.5. This figure shows that the hold period of the overload increases the plastic strain in the front of the notch root, thus it is higher than that without hold period. The increase of plastic strain by the hold period is higher on higher overload as shown in the case of 86 MPa. overload. When the load is proceeded to the constant amplitude load with R = 0, the tensile residual stress develops in the notch root, then the compressive residual stress develops on the lower level overload. When the stress ratio R = -1.5, the higher plastic strain leads to the increase of the tensile residual stress, hence as the plastic strain in front of the notch root is higher, the fatigue life is decrease. Because the shape of the notch root during the overload does not change as shown in Fig. 9, thus, in the present study the plastic strain related to the overload developing in front of the notch root is considered the only factor affecting the fatigue life.



(a).



(b).

Fig. 15. The plastic strain distribution

V. CONCLUSION

The fatigue life related to the crack emerging from the notch root is affected by the plastic condition developing after being overloaded in the notch root and in front of the notch root. Besides that, the condition of the constant amplitude load after the overload determines the residual stress state in the notch root and region in front of it. The plastic strain increases as the overload level increases in the region nearby the notch root affected by the overload. When the stress ratio of constant amplitude load is 0, the compressive residual stress develops in that region. However, when the stress ratio is -1.5, the tensile residual stress develops in the region. The compressive and tensile residual stress, respectively, increases and reduces the fatigue life. The higher level of the overload leads to the plastic strain developing in the region affected by the overload increases. The increase of the plastic strain may lower the compressive residual stress, and it increases the tensile residual stress. The hold period of the overload enhances the plastic strain in the region affected by the overload. In the case of stress ratio is 0, the combination high level of the overload together with hold period causes the plastic strain developing in that region is too high, as the result, the residual stress developing in that region is in tension state instead of compression. This is the cause of the reduction of the number of cycles required the crack to traverse in the region affected by the overload. In the case of stress ratio is -1.5, because the hold period of the overload enhances the tensile residual stress developing in that region, thus, the fatigue life is lower than that of the base.

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