Effect of pore size on fatigue life of a cast aluminum specimen using NDE & FEA

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Abstract

Non-destructive evaluation methods are generally employed to identify defects after a fabrication process is complete, thereby concluding whether the product is accepted or not (any repairs to be made). But this method proves ineffective when it comes to evaluating the properties of a component like tensile strength, fatigue etc. There are many approaches made to predict / calculate the fatigue life of a defective component. This work explains the evaluation of fatigue life of a cast aluminium alloy specimen using Non-destructive evaluation and Finite Element Analysis (FEA) methods using the knowledge of stress concentration factor. This work also shows the relationship between fatigue life of the component with respect to the defect size (spherical) which has a crucial role to play in acceptance criteria.

Introduction:

Aluminium& its alloys are used widely in many industries like aerospace, automotive industry etc due to its decent strength-to-weight ratio. But their fabrication processes requires considerable amount of skill when compared to the traditional steels. Casting of this metal/alloy should be done carefully in order to prevent any defects like gas pores, shrinkages pores to occur because presence of these defects can degrade the properties like tensile/yield strength, fatigue life of the product and so failure takes place pretty early than expected . But, in general, it is an arduous task to completely obtain a pure cast alloy without any defects unless additional costs are spent which makes the manufacture process very expensive. This means that some allowances are to be made. Hence, there are codes & standards set by popular organizations like SAE, ASTM, and ASME which says whether a casted product is to be accepted or not depending on the size, shape and type of defects obtained in the fabrication process. Non-destructive evaluation or Non-destructive testing plays a crucial role because all the information regarding the defects or the discontinuities is obtained here. But NDE can't help in directly determining the static properties like strength, life of the component, etc.

A general procedure carried out in any industry is: Firstly, a product is casted based on a particular standard given by the quality assurance department. This product or the component along with the acceptance criteria of that standard set by QA department is sent to NDE department where in the department uses different techniques to find out discontinuities and based on that, comparing the defect characteristics from acceptance criteria, the product is evaluated i.e. whether it is accepted or rejected.

However, there is a limitation in the procedure.A product after the fabrication process might contain some defects, due to which its structural properties might get degraded. These properties can't be directly found out using NDE. Also, in an industry, no attempts will be made to find out the properties of the final product containing small defects. So there is a possibility that a product might fail earlier than expected. Suppose, if an aerospace component is being manufactured, the acceptance criteria (generally taken by SAE standards) may or may not be present for that particular component. So the industry considers standards like AMS2442 which describes about "Magnetic Particle Acceptance Criteria for Parts", AS3071, AS1177 etc. Thus, individual concentration on a component is lost. For instance, a design engineer designs an aerospace component which can withstand around 40 million cycles of constant load without failure. When the component is manufactured, undergone NDE & QA procedures and after it is assembled to the main machine, this component might fail at less than 40 million cycles due to allowance of over-sized defects. So, in order to find out the fatigue life of that component without damaging it, a similar component of that material containing the same-sized defects must be manufactured and tested to obtain the life. But this proves to be arduous where a lot of time and money has to be invested.

There are many qualitative and quantitative explanations presented which could predict the fatigue life of the component with good accuracy. This work describes an approach to quantitatively evaluate the fatigue life of a specimen by employing Computed Tomography (CT) and Finite Element Analysis (FEA) method.

Approach:

The general way to commence is manufacturing the required component (in this case, a tensile test specimen) followed by CT scanning to obtain the characteristics of the defects. This CT image is reconstructed in 3D and FEA calculations are made to find out the stress concentrations at the discontinuities using simulation software in this case, ANSYS.

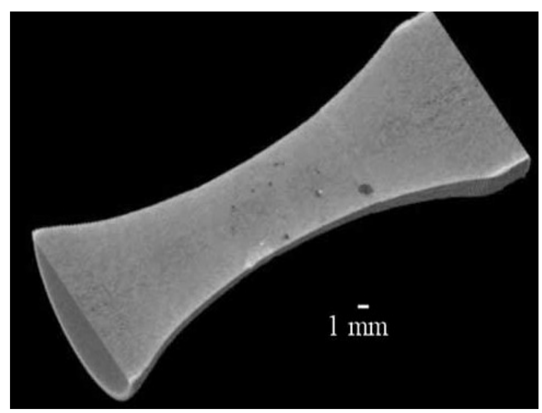

Fig 1.1 represents the CT image of a sample specimen consisting of defects.

This work has considered directly a model made from CAD drawing (Solid works) assuming it as the specimen obtained from casting with a spherical gas pore in it as shown in Fig 21. Now, the specimen is imported to ANSYS Workbench, in static structural condition, the boundary conditions are applied i.e. fixed support at one end and a pressure of 80MPa at the other side as shown in Fig 2.3. Now, the results are obtained maximum principle stress & Von mises stress values are evaluated as shown in Fig2.4.

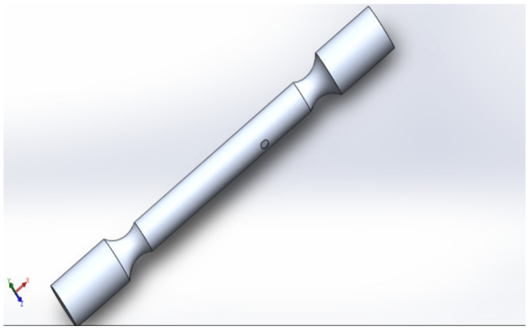

Fig 2.1 shows the standard specimen containing a gas pore (defect).

Now, the sample is imported to ANSYS workbench 15.0. The boundary conditions applied are as shown in fig3.1 i.e. it is fixed at one end and a stress of 80MPa is applied at the other. The equivalent /von-mises stress is found out as shown in the fig 3.2. A probe is inserted near the end of the pore to find out the stress value at that point as shown.

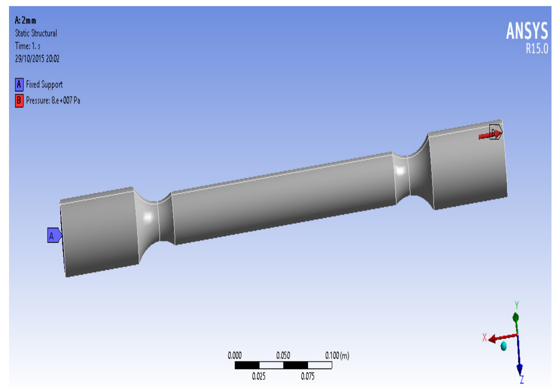

Fig 3.1showing the specimen with the boundary conditions applied.

Analysis:

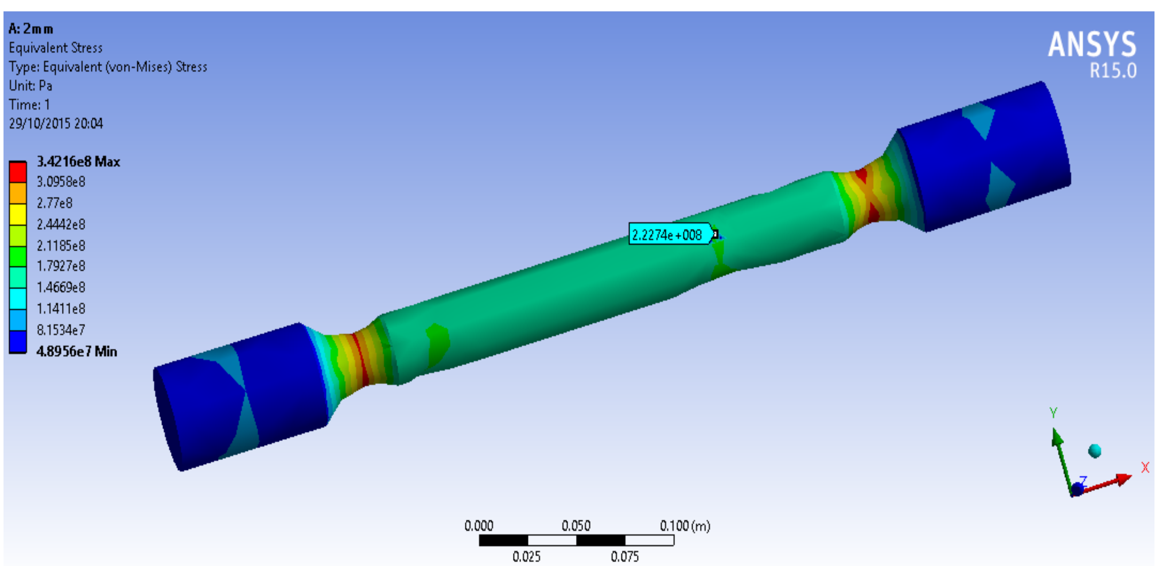

Fig 3.2 showing the equivalent stress obtained from the boundary condition

Results & Discussion:

From the above analysis, the stress concentration factor (K_t) can be found out. K_t is defined as the ratio of maximum principal stress or von mises stress obtained at the discontinuity to the nominal stress.Now, the fatigue stressconcentration factor (K_f) can be found out from $K_{f(pore)} = 1+\eta(K_t-1)$ Where η is defined as the notch sensitivity factor given by Paterson'sequation. $\eta = 1 \div [1 + (a \div r)]$ where 'a' is a material constant and 'r' is the radius of the defect.

Finally, the pore-prone specimen's life i.e. number of cycles to failure can be found by substituting the obtained values in the equation. $Ni = Nd(\frac{\sigma f}{\sigma i})^k$ [2] (or)

$$Npore = \frac{Nk}{(\frac{\sigma k * Kf(pore)}{\sigma pore})^{k}} [3]$$

Where N_k&σ_k are the No. of cycles to failure and the corresponding fatigue strength of defect-free 7075-T6 component. σ_{pore} is the stress level applied on the pore-prone specimen and k is the slope of S-N curve of defect-free 7075-T6 alloy. For a defect size of 2mm in the specimen, the life obtained is around 1.1e7 cycles which is similar to the value

Found out in [3]. A graph is drawn with radius in X-axis and life of the sample in the Y-axis as shown in fig 4.

S.no	Radius of the defect (mm)	Fatigue stress concentration factor (Kf)	No. of cycles to failure (10e7 cycles)
1	1	2.11	1.65
2	1.5	2.34	1.42
3	2	2.61	1.1
4	2.5	2.82	0.948
5	3	3.42	0.64
6	3.5	3.57	0.58
7	4	3.74	0.53
8	4.5	3.83	0.51
9	5	3.92	0.48

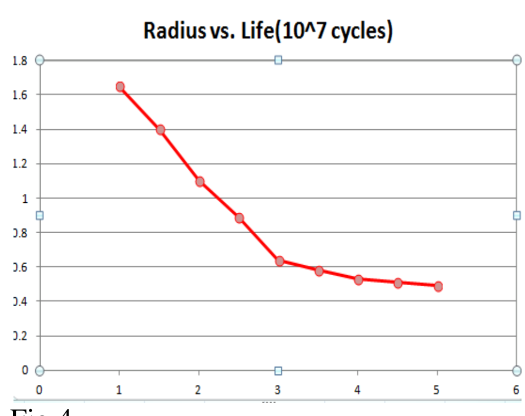

Fig 4

Conclusion:

Fatigue life of any component can be calculated with good percentage of accuracy provided we know the defect/pore diameter, its distance to surface and the fatigue data or S-N curve of the defect-free component of that material. However, due to the limitation that only CT proves effective when calculating the life, this method might not be employed everywhere. But due to tremendousresearch in this field, in the near future, there might be an economical way to obtain the required data without CT so that this approach can be carried out and the life of the component can be obtained without destructing the component.

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