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Investigation of failure analysis of EN24T T-welded joints under tension in structure

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ABSTRACT

The present study investigates the failure analysis of welded joint subjected to tensile loading with the help of experimental and analytical approach. The SEM and EDS methods are applied at failure surface of welded joint. The 3D model of welded joint is developed by using ANSYS software for simulation purpose. The welded joint deformation results from ANSYS is validated by using experimental data. There is a good agreement between analytical (ANSYS) and experimental results. The fractography study is carried out with the help of SEM method. The brittle and ductile fracture surface is observed at heat-affected zone. The chemical composition is determined using EDS method, the experimental outcomes represented that the T-joint is much stronger than the other joint. FE model is created by using SOLID187 elements. The stress sanguinity at junction of T-welded joint is studied. The failure load of present model is 30KN, these results are useful for designing the military aircraft structure.
Keywords: FEM, Experimental analysis, SEM, EDS, Stress Singularity, Welded joint for aircraft structure.

Introduction

The military aircraft wing structure is made of mild steel. Over recent years, Commission XIII of the International Institute of Welding (IIW) has been promoting research and developing the technical background required to develop a weld quality guideline which quantitatively relates weld acceptance criteria to the expected structural performance. Failure of the towing arm fork has been initiated by weld solidification cracking of the weld region at close to the fusion line.

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Nomenclature

σ_1 Principle stress

σ_{von} Von Mises stresses

SEM Scanning Electronic Microscope

EDS Energy Diffraction Spectrum

E Young Modulus (MPa=Mega pascal=N/mm^2)

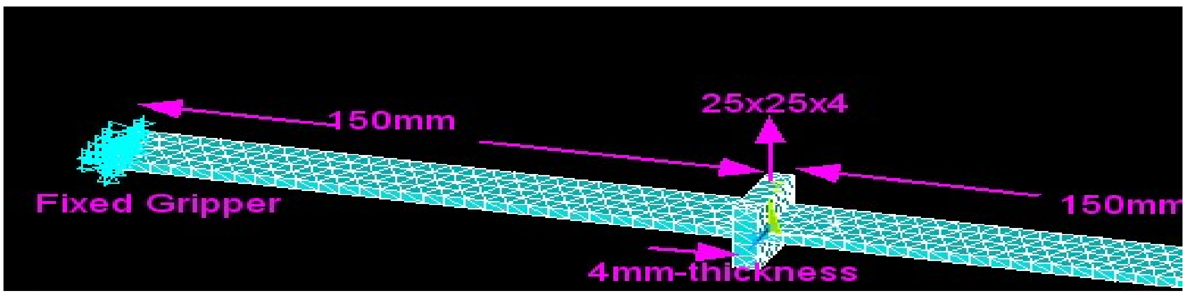
Modeling and numerical analysis of aircraft wing structure was studied by Pawer et.al [1]. The Liquation cracks at heat-affected zone (HAZ) have aggravated the situation further by weakening the microstructure and facilitating the crack propagation. The Grain boundary precipitates of Al-Cu-Fe type in HAZ have facilitated the propagation of failure along with the liquation cracking. On the other hand, Al-Fe-Mn type of precipitates sitting along the grain boundaries in weld area seems to have not facilitated the failure initiation unlike the solidification cracking. Hazra and Singh [2] described the metallurgical failure investigation of a failed towing arm/bar. Kurdelski et al. found that the aircraft life extension carries the inherent risk of adverse structural effects occuring as a result of fatigue [3]. They also focused on the effects that may lead to the structural damage or complete destruction of the aircraft. The study illustrated the possibilities of combining numerical analyses, nondestructive testing and component fatigue tests for the purposes of the main landing gear pull-rod damage investigation. A new model was developed by [4]. It proposed a novel methodology that allows a variation of a RS field in the specimen while keeping constant all other variables influencing FCPR. Different welding joints were used in aircraft wing structure presented by [5]. Clark [6] developed a strong capability as an impartial adviser on aviation failures to support (ADF) Australian Defense Forces self-reliance. The severe operating conditions for components in military aircraft provide a wide range of failure modes and introduce many factors which can influence those failures. The aerospace industry is undergoing an intense competitive pressure due to new market demands and regulations. Some aircraft engine manufacturers have thus adopted a fabrication approach to build their large structural components. Within fabrication, smaller parts are welded together into the final shape [7]. Raghavendra et al. conducted an experimental failure analysis of aircraft engine during service [8]. They focused on the connector as a fabricated tubular structure wherein the flanges were circumferentially welded to a bent pipe on both ends. Furthermore, the Welding Capability Assessment Method (WCAM) was presented as a tool to support the systematic identification and assessment of design issues related to product geometry critical to the welding process [9-10]. They have also focused on a list of potential failure modes during welding associated with the specific design parameters. The manufacturing process was optimized by using an advanced method given by [11-13]. A new weld class system has recently been developed as a Volvo Group Standard [14]. The new standard has three quality levels for fatigue: as-welded normal quality, as-welded high quality and post-weld treated quality. It contains acceptance limits which are consistent with the expected fatigue strength.

Therefore, many researchers have focused on aircraft structure failure regarding military purposes. We found a research gap indicating that in the military aircraft, wing structure fails at the welded joint due to tensile action of the load. During the uniaxial tensile process, a uniaxial tension test of EN24T steel T-welded joint is conducted in this research, and the fractography method is used to examine the fractures surface failure i.e. ductile or brittle. Moreover, FE model of the T-Welded joint is developed by using ANSAYS APDL 2021. In the present study, the experiment is conducted by the use of the digital UTM machine. The FE model is validated with the help of the experimental result, and stress singularity is reported in this study.

2. FEA (3D modeling and Simulations)

The FE model is developed by using computer system with the help of ANSYS 2021. The material properties of the steel EN24T are given by Tensile strength= 950MPa, yield strength= 650MPa, E=207GPa, and Density= 7840Kg/m3. The detailed dimension and boundary condition (BC) of FE model of the T-weld joint are represented in Fig. 1. (a). The T-welded joint FE model is meshed with SOLID 187 tetra hydron element. The total element size of the welded joint is 34720, which is the h-type of mesh employed for entire analysis. The stress concertation location at the center of the work is refine-mesh as depicted in Fig. 1. (b). It shows stress singularity is presented at the junction of two part, whereas refine mesh has been studied for the T-joint. The simulated welded FE model is shown in Fig.1. (c). It shows the deformation of the welded joint subjected to tensile loading. The stress distribution of the welded joint is shown in Figure 2. It represents the stress magnitude along to z-direction. The welded joint at center has no stress because it has a large support. There is much more stress at load application point such that the stress singularity concept is employed and such type of error can be minimized. The stress singularity is examined and tabulated (Table 1). The relation between stress singularity and load is shown in Figure 3. It is observed that the concentrated load increases by decreasing the stress singularity of the welded joints. The tensile load increases from 350N while the stress singularity remains constant. It does mean that FE model is stable and there is no need for refine mesh (stop refine mesh).

a)



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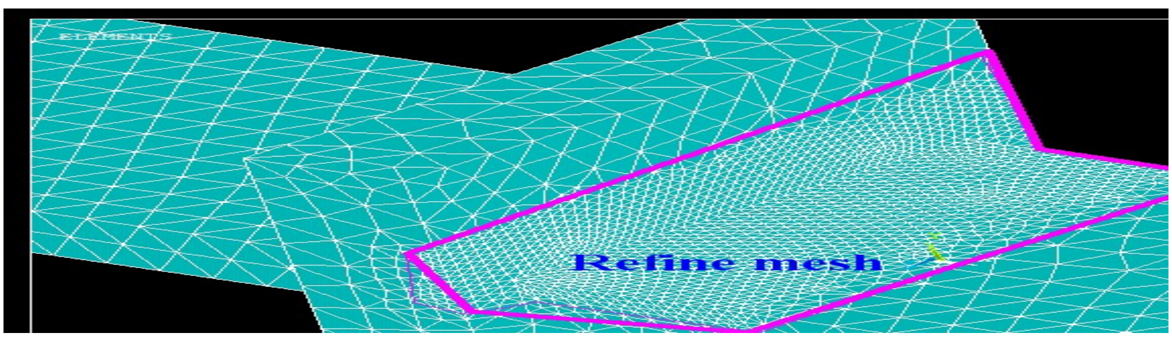

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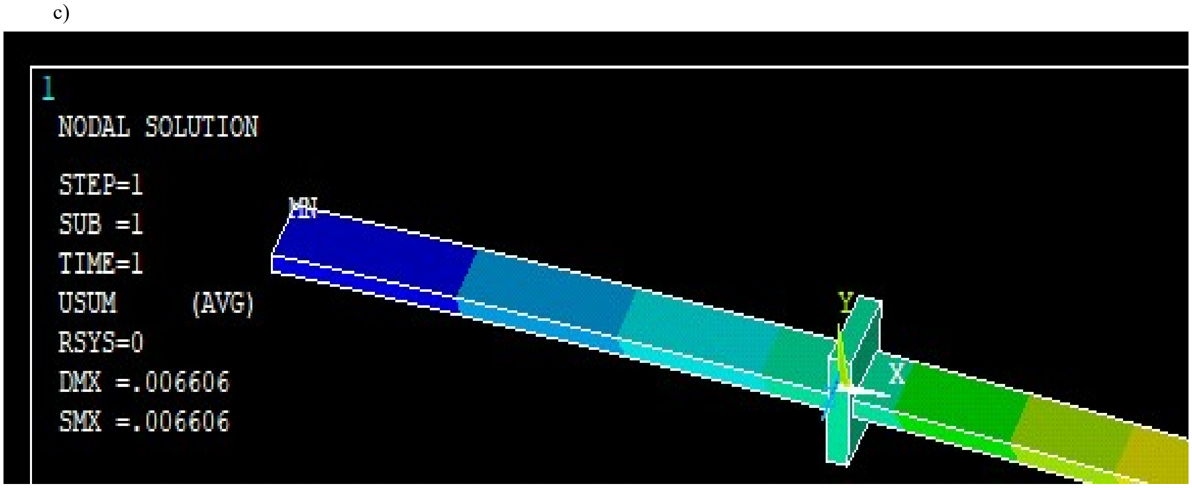


Fig.1. 3D-FE modeling and simulation is developed for T-joint welded structure: (a) Dimension of the welded joint ,(b) Refine mesh at stress singularity zone, (c) The deformation characteristic of Simulated 3-D FE model

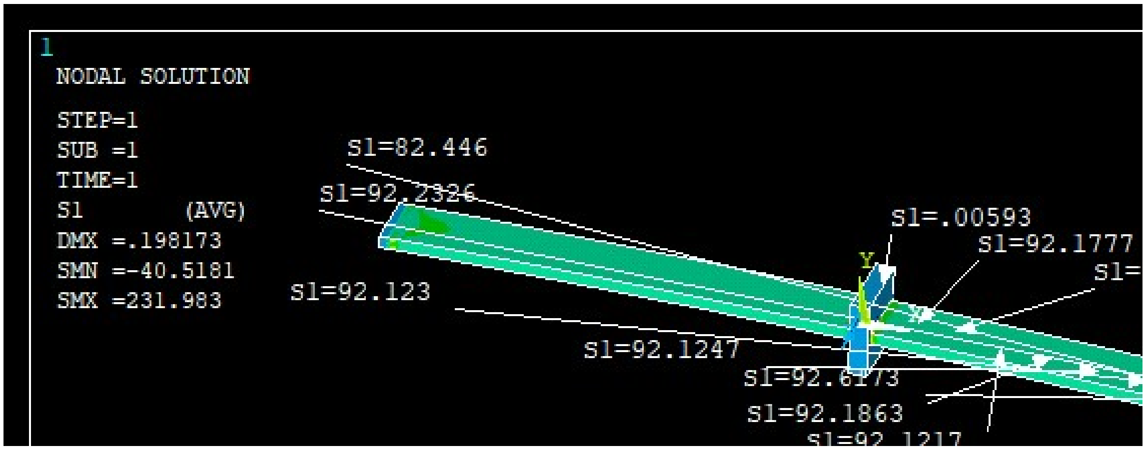


Fig. 2. Principle stress (σ_1) distribution at different locations of the welded specimen

Table .1 stress singularity for varying load for T-welded joint due to tensile

Load	Principle stress (σ_1)	Von Mises stress (σ_{von})	Stress singularity= $\frac{\sigma_{von}}{\sigma_1}$
100	38.2578	45.548	1.184211
150	77.2548	91.2458	1.181818
250	115.257	136.879	1.182609
300	154.656	182.264	1.178512
350	193.319	227.8325	1.178518
400	231.983	273.397	1.178522

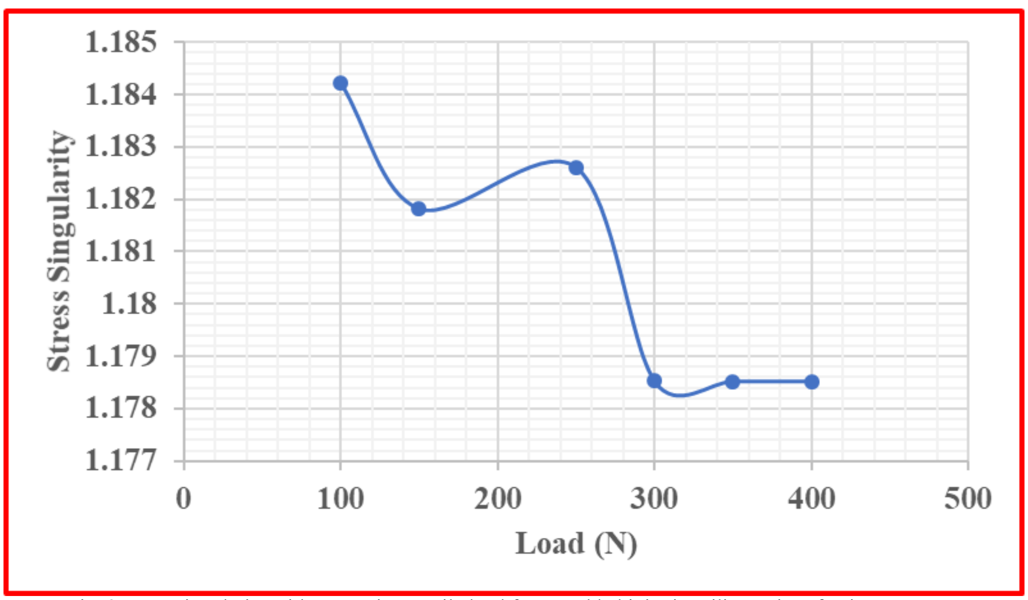


Fig. 3 stress singularity with respective tensile load for T-welded joint in military aircraft wing structure.

3. Experimental Results and discussion

3 .1 Experimental set-up for T-Welded joint under tension test

The workpiece is prepared by using the double V-shape for tensile test. The specimen welded joint was fabricated by won workshop. The tensile test of specimens was carried out on 100 KN capacity of the Universal Testing Machine (UTM) as shown in Figure 4. The detail specimen size is given in Fig. 1. (a). The speed of machine is given by 2 mm/min. The actual tensile load versus displacement is plotted in Figure 5. It is observed, that the T-welded joint is the failure at a 30KN load. The numerical value of the experimental results is given in Table 2. It is shown that FE results are very close to the experimental results. So, the present FE model is in a good agreement with the experimental results.

Table 2. Deformation with respective load for experimental and ANSYS results

Experiential		ANSYS	
Load (N)	Deformation (mm)	Load (N)	Deformation (mm)
800	0.013212	800	0.012829
5000	0.019817	5000	0.019242
10000	0.033029	10000	0.032071
15000	0.33254	15000	0.322896
18000	3.30288	18000	3.207096
21000	4.62403	21000	4.489933
29258	5.2548	29258	5.254800
500	5.2733	30254	5.120374

Fig.4. Experimental analysis by using UTM machine

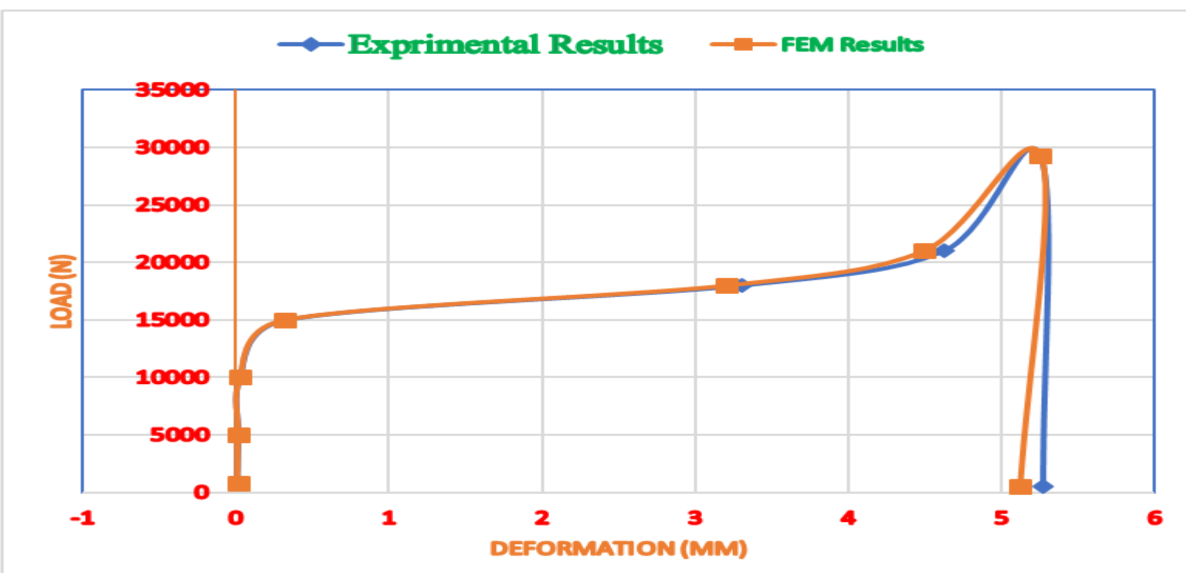


Fig. 5 Load versus Deformation curve for T- welded joint for tensile test

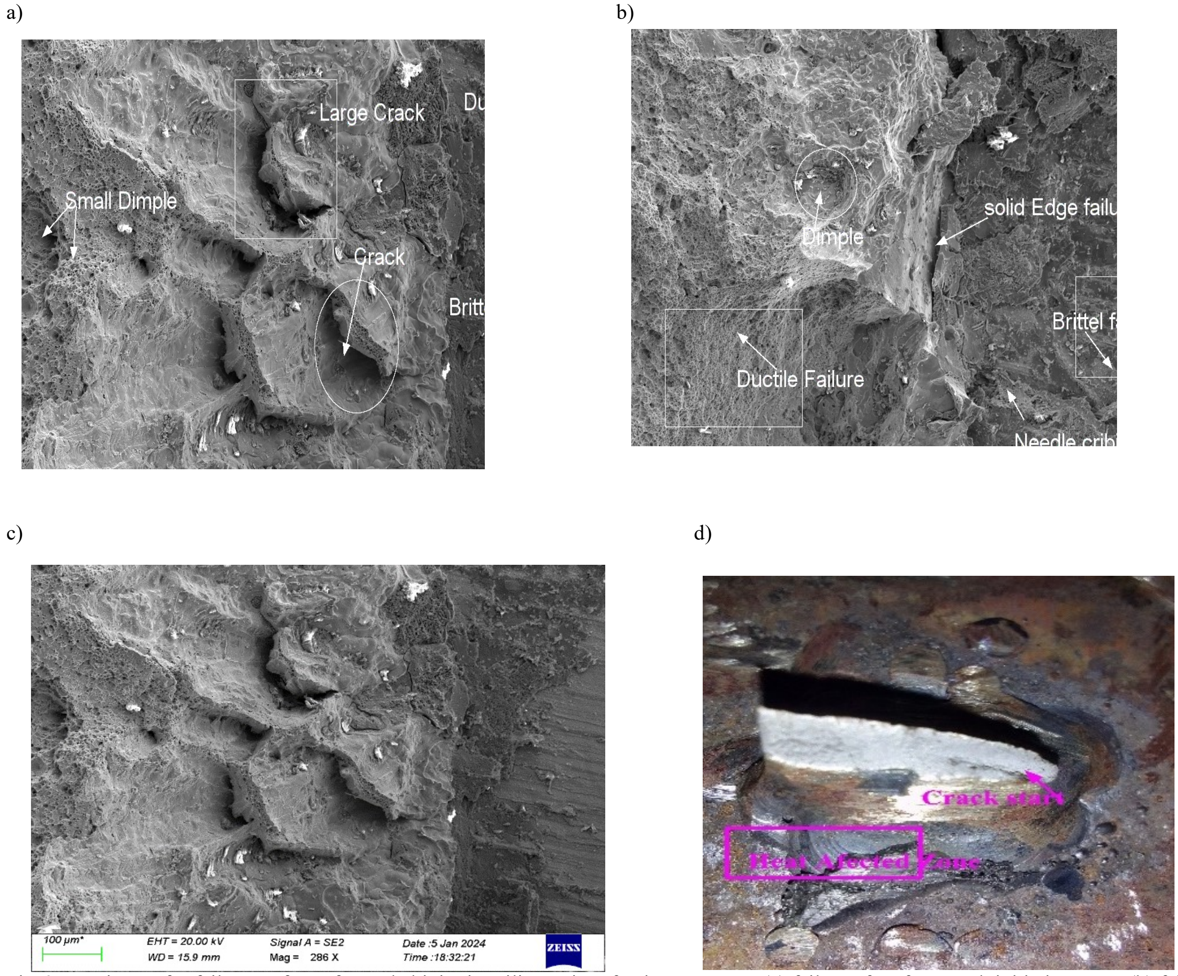
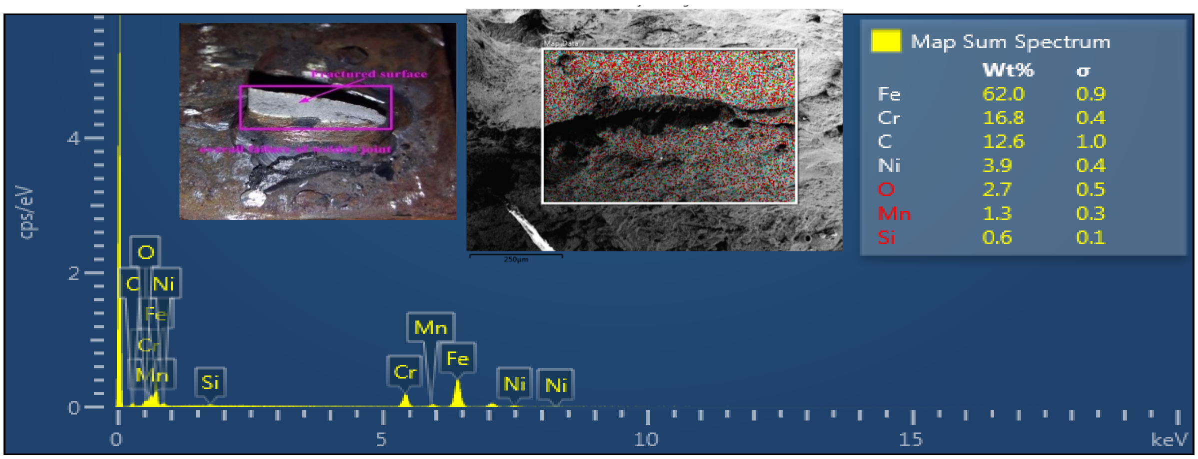


Fig.6 SEM image for failure surface of T-weled joint in military aircraft wing structure: (a) failure of surface crack initiation zone, (b) failure surface at Heat-affected zone, (c) failure surface at complete fracture zone, (d) Actual failure surface of weled joint

3.2 Fractography

The fracture of surface is systematically examined by using SEM method. After failure, the welded part is examined using SEM method. During SEM analysis, the failure surface divide into two mode of failure, first mode- ductile failure, second mode brittle failure of welded joint were investigated. The failure of surface crack initiation zone is approximately 10 mm wide. The fracture morphology of welded joint is shown in Fig. 6. (d). This zone comprises of varying morphology. Vicinity of the failure of surface crack initiation zone shows the trans granular mode of fracture although some grain boundaries are still visible. Moreover, the area near brittle fracture pattern shows the river line pattern as depicted in Fig. 6. (a). Some regions of small dimple also show a ductile morphology. So, it could be concluded that the large crack, brittle and ductile fracture is presented at the failure of surface crack initiation zone. The heat-affected surfaces are examined by SEM Fig. 6. (b) . The surface covered by cracks may have been formed because of the high-pressure, oxygen-enriched atmosphere, which markedly accelerated the heat rate as well as the internal stress generated during welding process. Fig. 6. (b) shows fracture at the heat-affected zone. Hence, heat-affected zone was observed weaker as compare to another zone, so that zone starts crack propagation of welded joint. Microstructure at heat-affected zone was observed to be needle-like grain boundary structure. The centre crack is observed at heat-affected zone. The failure surface at complete fracture zone penetrates to the metal surface and increases the possibility of the localized fracture over the width of the specimen. Given that the time before the leakage occur is short, the pits develop rapidly after nucleation in the high-pressure, oxygen-enriched atmosphere. The predominant large fracture and ductile failure are observed as shown in figure 6(c). Finally, the morphology of failure surface at complete fracture zone, The failure at welded joints mainly contained Fe=62%, Cr=16.8%,Ni=3.9%, Mn=1.3 and Si=0.6 by using performed EDS analysis after failure surface of the welded joints. EDS pattern is presented in Fig.7(a) in this case Cr is maximum. These components are very similar to those formed in mild steel, indicating that the oxygen-enriched atmosphere in the welded joint did not greatly shift during welding process. Weight percentage of chemical component is depicted in Fig.7(b). Similarly, EDS results for failure surface at heat-affected zone are shown in Fig. 8 (a-b). The detail of chemical contains at heat-affected zone is given by, Fe=78.55%, C=9%, Cr=6.9%, Ni=2.5%, Si=0.4%, Ti=0.1%. The carbon accumulated at the heat-affected zone of the welded joint, which was approximately 9%. Finally, the EDS method has evaluated a deep failure for heat-affected zone when amount of Cr is smaller, so this region is going to be ductile failure mode.

a)



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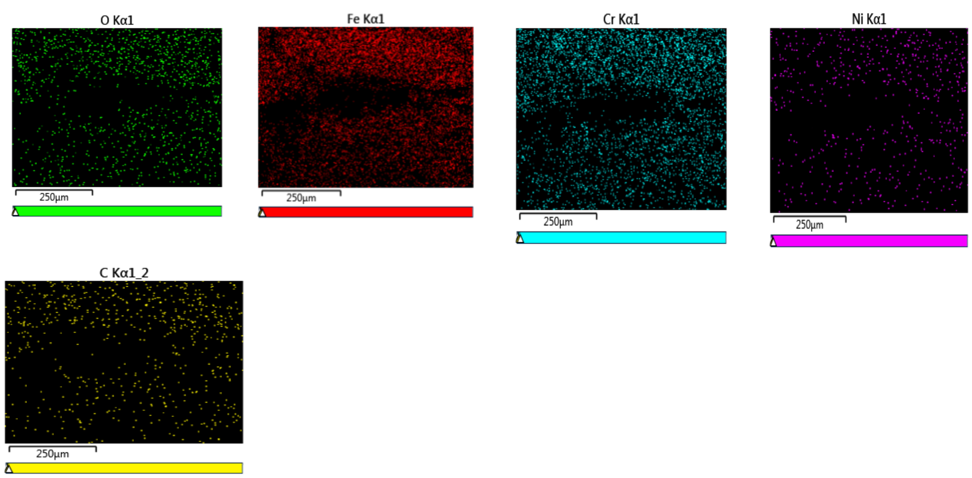
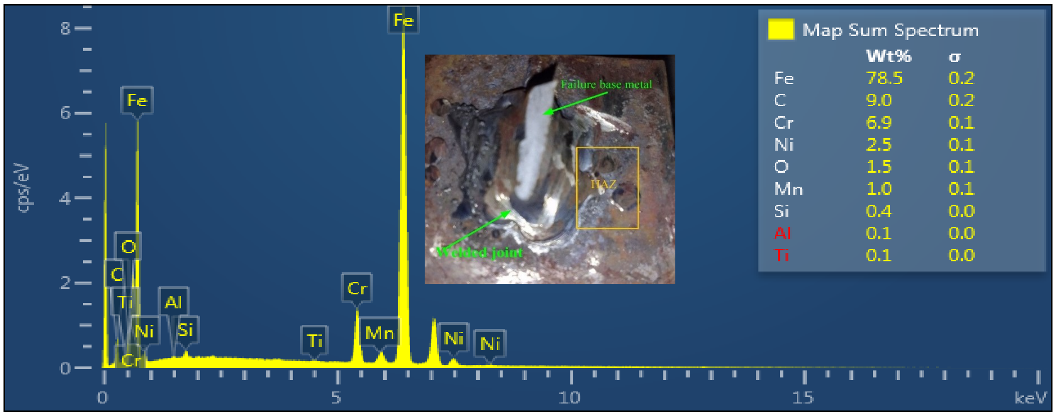


Fig.7 DES analysis of weled joint for failure surface at after fracture zone: (a) EDS image at failure surface at after fracture zone, (b) different chemical componenet at failure surface at after fracture zone

a)



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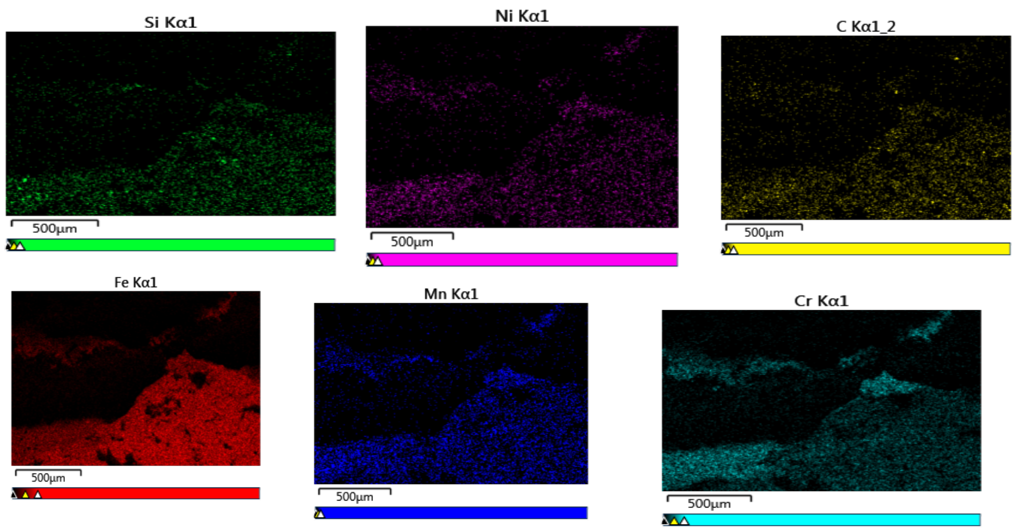

Fig.8 EDS analysis at heat-affedted zone under failure occured weled joint for different chemical compositions: (a) DES analysis at failure surface at heat-affected zone, (b) different chemical componenets at failure surface at heat-affected zone

4. Conclusion

In this research article, failure analysis of the T-welded joint in military aircraft wing structure under uniaxial tension loading was studied. The failure has been reported through experimental and analytical approaches. The 3D FE model is developed for T-Welded joints. The model is validated by experimental results obtained from the UTM. The experimental results and FEM results are in a very good agreement. The following conclusions may be drawn:

a) Stress singularity decreases with increasing load.

b) The failure surface of the welded joint is systematically examined by using SEM method.

c) The T-type of welded joint is very stronger than the other joints such as Butt, Lap and Corner joints.

d) T-type of weld failure at load is 30KN, which value can be useful to the design engineer of military aircraft structure.

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