Introspection of a Failure Analyst

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Failure of an engineering component is a condition when it no longer is able to perform the desired function due to a breakage, fracture, crack, wear, corrosion, inaccuracies as regards dimensional or other parameters. In a large number of engineering failures, it has been noticed that unsuccessful or non-performance of an engineering system is due to failure of one or more components of the assembly. During preliminary examination, the system's manager is generally able to locate the component that is suspected to have caused the failure. Whenever there is a crack or fracture, telltale evidence is left on the failed component. In certain cases, when there is a rubbing action by the mating fracture surfaces or rubbing of the fracture surfaces by some other component, it amounts to loss of useful evidences for an analyst. In such a situation, a failure analyst has to resort to the available data and circumstantial evidences to draw a conclusion about the failure. A good failure analysis can be highly useful in understanding the cause of failure and also the methods to prevent occurrence of such failures in future.

Failure analysis is a combination of art and science. All material scientists or engineers cannot handle failure analysis as it needs certain amount of experience and skill to handle a case study. Since every failure is reported as a crisis, it is also expected to get an investigation carried out within a very short time. However, it should be borne in mind that a failure analysis cannot be performed with a magic wand. The analyst requires a certain amount of time to understand the background, collect suitable samples, make a variety of specimens for a large number of tests, interpret the test results and then come to a conclusion in order to pronounce the cause. Failure

We all have to decide for ourselves what constitutes failure, but the world is quite eager to give you a set of criteria if you let it-J. K. Rowling.

analysis is based on sound metallurgical principles and authentic scientific evidences gathered through standard tests. The time frame demanded by the analyst should be considered to be genuine and must be provided for a job to be well handled. After all everyone involved in the case looks forward to the cause of failure and a suitable remedial measure in order to avoid future recurrence of the same.

'Neglect of metallurgy' has been the primary reason for a large number of failures of metallic components in our country. Most of the small and medium scale industries appoint mechanical engineers in all such fields of shop floor to look after the metallurgy related activities also, to optimize the man power requirements and for cost effectiveness; for example, a heat treatment shop. During the design and development of a system, for example, a weapon, ordinance or an aerospace vehicle, metallurgists or materials experts are seldom part of the team. When some component of the system fails, the management appoints an inquiry committee to look in to the matter. More often than not, this committee comprises of members from the design, manufacture and user. A metallurgist is not appointed, many a time, as one of the members in the inquiry committee to the management while his services are sought for investigation. It is made to believe by the inquiry committee to their management that a metallurgist is appointed to carry out a few metallurgical tests under their instruction. In a number of instances, the failure analysis report prepared by the analyst is not presented in its actual form by the inquiry committee to their management, whereas portions drawn out of it for convenience makes in to the final outcome of the inquiry committee report. During and after the course of investigation, the failure analyst is called to attend the deliberations of the inquiry committee only in the capacity of an 'invitee' and not as a member of the inquiry team only to seek clarifications on the failure analysis report. There are other instances where the engineers of the development team arrive at a cause of failure based on the operational error or breakage of some part of the system. Now they approach a metallurgical laboratory with a

OLD ACADEMICS never die; they just lose their faculties

request for chemical analysis of the failed component and sometimes for a hardness check. The inquiry committee thinks that it knows the cause of failure and what more they want is a confirmation by a chemical analysis or hardness check. Even at this stage, the committee does not realize that what it requires is a failure analysis by an expert. What it also does not realize is that it needs to approach a materials consultant for a thorough failure analysis and appointment of a metallurgist for all future endeavors. This non-realization leads to failure after failure but fails to wake up any establishment to understand its basic fault- 'neglect of metallurgy'. The day this realization comes and metallurgists get the right place in engineering industries and engineering systems development team, the problem of premature failure would minimize to a large extent.

Another important aspect is the lack of awareness about 'metallurgy' as a branch of engineering. In India and especially in southern India, the awareness about metallurgy/ material science as an engineering course is hardly found with both parents/students and engineering colleges. This is evident from the fact that a handful of colleges are running an undergraduate engineering course in metallurgy/materials science. The feeble job prospect for metallurgy graduates also dictates the poor existence of this course or its popularity. Moreover, failure analysis is only an optional subject in post graduate course in metallurgy. Bodies like AICTE and UGC should spread awareness among universities and suggest them to run metallurgy/material science course in at least 10% of the engineering colleges affiliated to them. Policy makers must see to it that such engineering graduates find suitable jobs in government and public sector engineering industries and establishments.

Most of the failure analysts, who are largely metallurgists working in this

I can't give you a sure-formula for success, but I can give you a formula for failure: try to please everybody all the time-**Herbert Bayard Swope**

field, have entered it as a matter of chance. They then struggle to learn the subject and skill, and later gain expertise by practising it over a long period. The users always are benefited from the work of a failure analyst but the analyst or his work seldom enjoys the recognition for his effort.

It is high time that failure analysis departments are created both at state as well as at the central level by the respective governments under a relevant ministry. It must be made mandatory for all government and public sector establishments to address their failure cases to this department and get them analysed and also implement the remedial measures suggested by it. That alone will impart seriousness to this important field of work and bring glory to both the work and the personnel rendering this yeomen service to the nation.

About the author:

Dr. K.P.BALAN obtained his M.Tech. from IIT, Kharagpur and Ph.D from Banaras Hindu University, Varanasi in Metallurgical Engineering. He joined DMRL, Hyderabad in the year 1982 and since then has been working in the area of Failure Analysis. He has handled over 300 failure case studies pertaining to defence hardware, railways, thermal power stations, mines etc. He has been a member of renowned national committees that addressed failure cases of strategic importance. He has been a member of Materials Standardisation Sub Committee, under Directorate of Standardization, and Sectional committee on Microstructure and Heat Treatment, under Bureau of Indian Standards (BIS), for one decade. He is a member of Metallurgical Engineering Division Council, of BIS. He has about 50 publications to his credit in national and international journals on topics related to failure analysis and structure-property correlations in steels.

Success is not the result of spontaneous combustion. You must set yourself on fire. - **Reggie Leach**

FAILURE OF ALUMINIUM ALLOY ADAPTER IN FATIGUE TESTING

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BACKGROUND INFORMATION

A broken part namely "Adapter" was forwarded to the laboratory for defect investigation. The adapter was a part of the fixture used for fatigue test assembly of a composite part "*Rescue Hoist Installation Beam*" of a military helicopter. The adapter was not meant to fail but was found cracked after completion of 5890 cycles during the fatigue test. The adapter was made of aluminium alloy of specification 3.1354. The adapter material was in T351 temper (heat-treat) condition. The adapter was fabricated through machining route from raw material stock.

OBSERVATIONS

Photograph of the as-received adapter that had failed during the fatigue test is shown in Fig.1. Failure had taken place at a location just above the change in section in the part. Close-up view of the failure location is given in Fig.2. The fillet radius at the change in section did not appear to be very sharp and was having sufficient radius/relief.

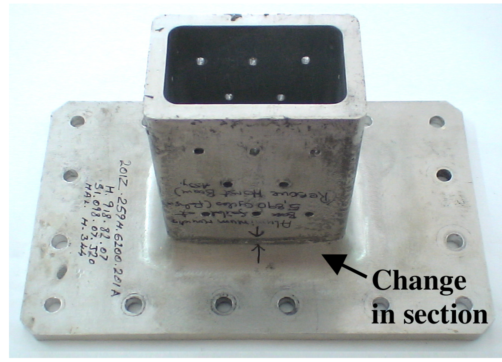

Fig.1: Photograph of the part adapter that had failed during the fatigue test

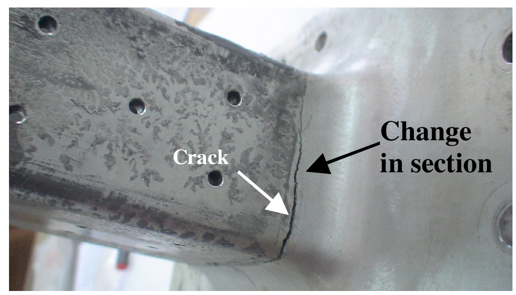

Figure 2: Close-up view of the failure location in the adapter

Chemical analysis

The chemistry of the adapter was analyzed by spectrometry (Table.1). The composition conformed to 3.1354 specification requirement.

Table 1
Chemical composition of the adaptor

Elements	Weight (%)	
	Observation	Requirement
Si	0.05	0.50 (max)
Fe	0.09	0.50 (max)
Cu	4.05	3.80-4.90
Mn	0.48	0.30-0.90
Mg	1.41	1.20-1.80
Cr	0.014	0.10 (max)
Zn	0.03	0.25 (max)
Ti	0.03	0.15 (max)
Al	Bal	Bal

Hardness Measurement

The hardness of the adapter was measured in Brinell Scale as per ASTM E 10 using 2.5 mm diameter ball and 62.5 kg load. The average hardness of the adapter material was about 127 HBW. This is higher than the minimum requirement of 110 HBW in T351 temper condition.

Microscopic examination

Sample was sectioned from the adapter at locations close to and away from the failure location for microscopic studies.

The sectioned samples were appropriately mounted, polished and etched for optical microscopic studies. 3.1354 is a wrought aluminium alloy specification. Hence, it is expected that the adapter shall reveal completely wrought microstructure.

However, microscopic examination revealed presence of remnant cast structure in the microstructure of the adapter material. Photomicrographs showing presence of remnant cast structure in the sample sectioned away from the failure are shown in Fig.3. The sample sectioned close to the failed location revealed significant level of cast/dendritic structure (Fig.4).

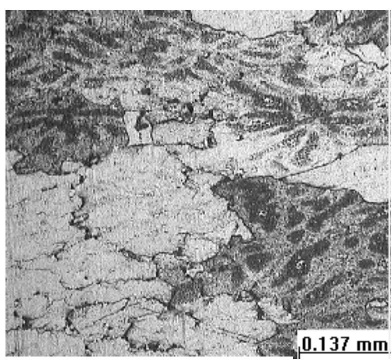

Fig.3.Remnant cast structure in the sample sectioned away from the failure

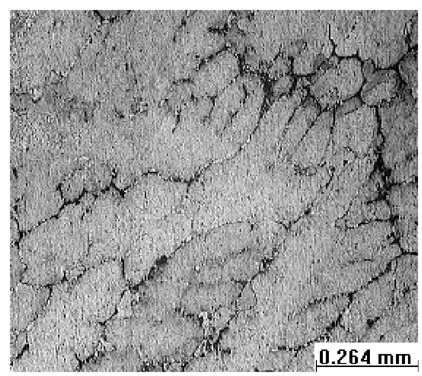

Fig.4: Significant level of cast structure in the sample sectioned close to the failure in the adapter.

Fractography

The fracture surface of the part was examined under stereo-binocular microscope. Macro examination revealed that major portion of the fracture surface showed fibrous features that is indicative of overload failure. However, careful examination revealed small areas on the fracture surface that showed features of fatigue failure like half moon zones. These areas were located close to the outer surface of the part. From the gross fractographic features, it appeared that the fatigue failure had originated at multiple locations from the outer surface of the adapter. However, to confirm the mode and initiation of failure, the fracture surface of the adapter was examined under *Scanning Electron Microscope (SEM)*.

Scanning Electron Microscopy

Macro examination had revealed features of fatigue failure on the fracture surface at locations close to the outer surface of the adapter. Hence, the fracture surface close to the outer surface of the adapter was carefully examined under SEM. SEM analysis revealed presence of half moon zones at many locations on the fracture surface. Half moon zone is indicative of fatigue failure. SEM images showing half moon zone on the fracture surface at

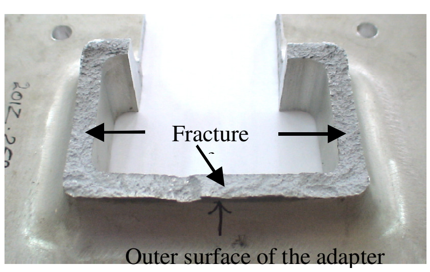

Fig. 5: Fracture surface obtained after opening the crack in the adapter

locations close to the outer surface of the adapter are given in Fig.6.

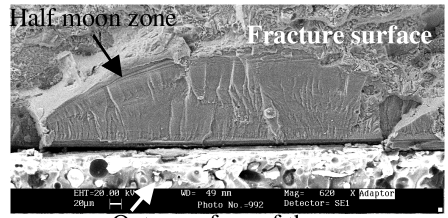

Fig.6: SEM images showing presence of half moon zones on the fracture surface at locations close to the adapter outer surface

The areas of the fracture surface showing half moon zones revealed presence of striations when examined under SEM at high magnifications. Striations are typical of fatigue failure. High magnification SEM images showing presence of fatigue striations on the fracture surface of the adapter are given in Fig.7.

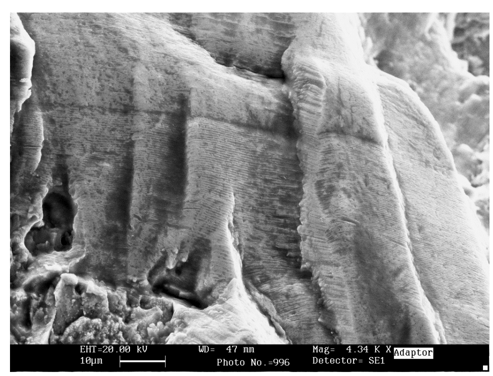

Fig.7: High magnification SEM images showing presence of fatigue striations on the fracture surface of the adapter

The half moon zones and orientation of the fatigue striations confirm the fact that small fatigue cracks had initiated at multiple locations from the outer surface of the adapter.

Rest of the fracture surface revealed dimpled features (Figure 8) that is indicative of overload failure and corresponds to the fast/final failure of the adapter.

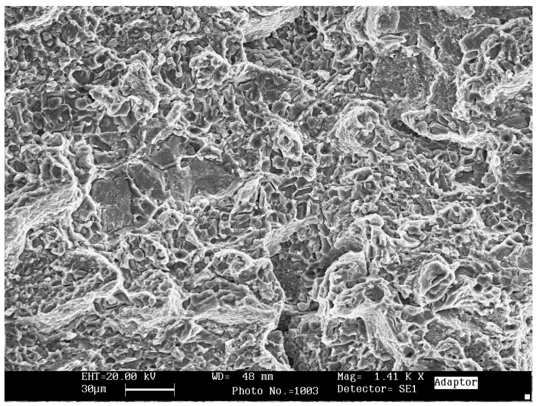

Fig. 8: High magnification SEM image showing presence of dimpled overload features on the fracture surface of the adapter

ANALYSIS OF TEST RESULTS

1. Chemistry of the adapter conformed to the specification 3.1354.
2. Average hardness of the adapter was about 127 HBW which is higher than the minimum requirement of 110 HBW in T351 temper condition.
3. The alloy, 3.1354 is a wrought aluminium alloy specification. Hence, it is expected that the adapter material shall revealed completely wrought microstructure. However, micro examination reveal presence of remnant cast structure in the adapter material. Further, at locations close to the failure, the adapter material revealed significant levels of dendritic (cell) structure.
4. The adapter was manufactured from the raw material stock by machining. The raw material used for machining was identified as the source of remnant cast structure in the adapter.
5. The presence of remnant cast structure in the raw material was attributed to insufficient working (viz. extrusion or rolling or forging) of the cast billet that was used to produce the raw material stock. Owing to insufficient working, the cast structure of the billet had not broken down completely. This had resulted in presence of remnant cast (dendritic) structure in the raw material stock that was used to manufacture the adapter.
6. The adapter had cracked at a location just above the change in section (radius) in the part. Fractographic studies revealed that failure in the adapter had

initiated in the form of small fatigue cracks originating at multiple locations from the outer surface of the part. Later, the component had fractured by overload (fast) failure.

7. In principle, for a given metallic material, completely worked structure is believed to have better dynamic properties especially fatigue when compared to that of cast structure. Hence, from the observations and with the available evidences, it looked apparent that the remnant cast (dendritic) structure observed in the adapter material has resulted in its premature failure during the fatigue test.

CONCLUSIONS

The failure of the adapter had initiated by multiple small fatigue cracks originating from the outer surface of the part. On further servicing of the component, it fractured by overload (fast) failure.

Remnant cast (dendritic) structure observed in the adapter material appears to have caused the unexpected failure of the adapter during fatigue test. The raw material stock used to manufacture the adapter was identified as the source of remnant cast structure.

Due to insufficient working, the cast structure of the billet had not completely broken down and had resulted in remnant cast structure in the raw material used to manufacture the adapter.

RECOMMENDATIONS

In order to obtain more homogeneous microstructure free from abnormalities like remnant cast structure in the part, it is recommended to manufacture the adapter by forging route rather than direct machining from raw material stock or ensure that the raw material used for machining is free from any cast structure

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About the authors

Dr R.Raghavendra Bhat took M.Tech. in Process Metallurgy in 1986 and followed with Ph.D. (Metallurgical Engg) in Thermomechanical treatment of spinodal Cu-Ni-Cr alloys in 1993. Starting his career as a Research Associate in Regional Research Laboratory, Trivandrum with a project on Secondary processing of Metal-matrix composites containing SiC_p and carbon fibre reinforcements, he further continued as a research fellow in the study of "Role of Al-Ti and Al-Ti-B master alloys in the grain refinement of Al and its alloys for defence applications" at I I T Kharagpur until 1995. His work culminated as an Indian Patent on the product. He executed the project on development of MMCs as Armour material during the period 1995 –2001 while working in the Materials Processing Division at National Metallurgical Laboratory, Jamshedpur. He moved to Central Materials & Processes Laboratory, F&F Division, HAL, Bangalore in 2001. He looks after mechanical testing and metallurgy sections responsible for process and service related investigation reports and finalization of report related to process & development, R&D projects, member of the team in the export projects from Rolls-Royce, MOOG, Honeywell Phoenix, Hamilton-Sundstrand USA, Turbomeca, France, Kaveri. He has published more than 50 papers in reputed Journals and presented equal number of papers in national seminars/conferences. He received "2011 Metallurgist of the Year Award" from Ministry of Steel, Govt of India on 14-11-2011 at Hyderabad. He is the Vice Chairman of IIM, Bangalore Chapter and Secretary, ASM International Bangalore Chapter.

Miss. Vaishakhi Nandi completed BE (metallurgy) from MS University of Baroda in 2000 and continued further with M Tech from IIT ,Bombay. She joined as Deputy Manager (Lab), Central Materials and Processes Laboratory, Foundry & Forge Division, Hindustan Aeronautics Limited (HAL), Bangalore in 2002. Since then she has been engaged in the following R &D work:

i) Failure Analysis of in-service and process failures of aeronautical & general engineering components.
ii) Metallurgical characterization of metallo-ceramic friction materials used in braking applications, shape memory alloy (NITINOL) ferrule rings and other aircraft spares as part of indigenization (development) activities.

She is a recipient of the following awards/Recognitions

i) Received Young Metallurgists of the Year 2009 award from Ministry of Steels, Government of India in November 2009 during NMD-ATM 2009 held in Kolkata
ii) Received Women Achievers award from *Forum of Women in Public Sector* (WIPS) under the aegis of SCOPE during 21st National meet of WIPS at Chennai in February 2011.
iii) Received first prize for oral presentation of the technical paper "Case study on failure of Casing Ring of Integrated Dynamic System of a military helicopter" at NMD-ATM 2011 organized at Hyderabad in the November 2011

She has published more than 15 technical papers in well-known journals and presented more than 30 technical papers in various international and national conferences/seminars.