11TH INTERNATIONAL SCIENTIFIC CONFERENCE
ON DEFENSIVE TECHNOLOGIES
OTEH 2024
Serbia, Tara, 9-11 October 2024

FAILURE ANALYSIS OF WELDED JOINT BETWEEN ROCKET MOTOR CASE AND FINS

ALEKSANDAR ĆITIĆ
Military Technical Institute, Belgrade, woteusrb@gmail.com

NADA ILIĆ
Military Technical Institute, Belgrade

MAJA MLADENOVIĆ
Military Technical Institute, Belgrade

VESNA PEJOVIĆ
Military Technical Institute, Belgrade

Abstract: *In this paper a fractured welded joint between rocket motor case and fins was examined. The goal of this study was to determine the cause of fracture which occurred during high pressure probe. Specimens taken from the fractured surface were examined using scanning electron microscope. In order to determine material properties and welded joint quality, chemical analysis, microstructural examination, and microhardness measurements were performed. Macroscopic examination showed that initialization of fracture was on outer surface of the case. Observations of fracture surface using SEM revealed mixed mode of failure, lamellar cleavage, and ductile rupture, without visible plastic deformation. Spherical particles based on Fe and O were also seen on fracture surface. Microhardness measurements showed high difference in microhardness value between base material and heat affected zone (HAZ). Detailed analysis showed that inadequate preparation and welding procedure resulted with unsatisfactory microhardness distribution which led to fracture.*

Keywords: *welded joint, fracture, microhardness*

1. INTRODUCTION

Welding is a technological process of joining two or more metal pieces using heat or pressure. Currently, welding is fast replacing other joining processes and is extensively used for fabrication of many differently components and structures such as missile and rocket parts, ships, bridge structures, pressure vessels, storage thanks etc. Since there is heat input during welding, consequently there are changes in metals microstructure around weld joint. This nonuniform microstructure across welded joint leads to nonuniform mechanical characteristics that can affect joint behavior during exploitation. Welding can also introduce defects in material such as pores, slag inclusions, etc. which all have negative effects on quality of welded joint. Failures of welded joint can have profound consequences on the safety of people and can produce financial loses. Thus, finding the cause of failure can help in avoiding such scenarios in futures and lead to improving welding practices (1-2).

Research presented in this paper deals with a failure of welded joint between rocket case motor and fins, which failed during high pressure probe.

2. EXPERIMENTAL PROCEDURE

The chemical composition of base material of rocket case meets the requirements for 42CrMo4 steel according to standard SRPS EN 10083-3 (3). The chemical composition of rocket case material is presented in table 1. Samples for microstructural analysis were prepared using standardized preparation process, wet grinding up to P1200 grinding paper and fine polishing up to 1μm diamond paste. After etching with 3% Nital solution, samples were observed under Leica optical microscope. Microhardness was measured by Vickers method (HV1) and is performed on samples taken from the fractured and non-fractured regions. Leica stereo microscope was used to observe the major features of the fracture surface and was documented by photographs. Scanning electron microscope (JEOL 6010LV) was used to detect the fracture morphology while energy dispersive spectrometer (Oxford instrument X-Max) was used for elemental analysis of fracture. It should be noted that EDS is semi-quantitative analysis. Heat treatment of sample taken from welded joint was performed in laboratory Heraus furnace on 500°C for 45 minutes after which sample were cooled on still air to room temperature. Used welding technique, welding parameters and filler material are not known.

Corresponding author: A. Ćitić;
E-mail: woteusrb@gmail.com
DOI: 10.5937/OTEH24103C

Table 1. Chemical composition of rocket case material

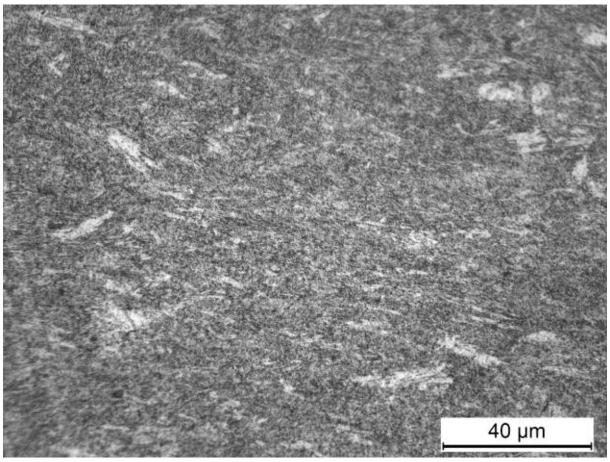
Element	Rocket case material mass%.	Standard requirements
C	0,43	0,38-0,45
Si	0,27	max 0,40
Mn	0,76	0,60-0,90
Cr	1,1	0,90-1,20
Mo	0,18	0,15-0,30
P	0,011	max 0,025
S	0,014	max 0,035
Fe	Balance	Balance

3. RESULTS

3.1. Microstructure analysis

Microstructure analysis was performed on the sample taken near the fracture initiation site. Microstructure of sample is shown on figure 1.

HAZ microstructure, consists of martensite. Microstructure of base material of motor case is fine grained tempered martensite.



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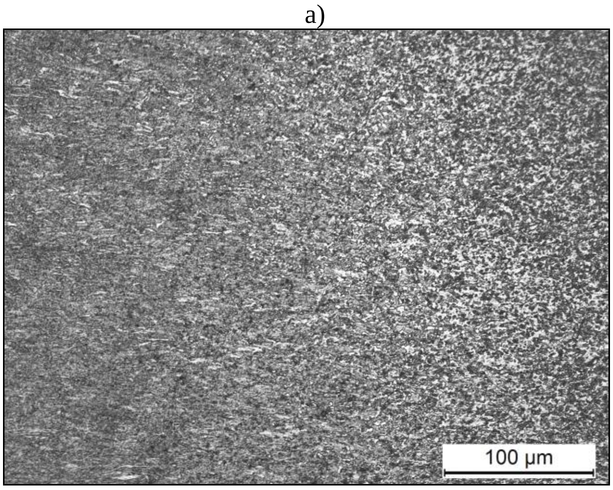

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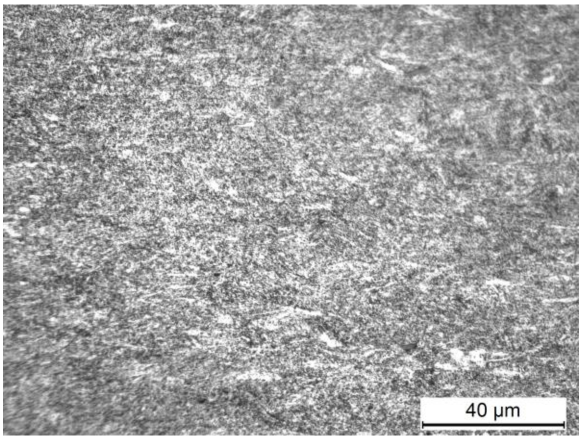

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Figure 1. Microstructure of a) HAZ near fracture initiation site, b) at HAZ/BM border and c) base material of rocket case

3.2. Microhardness measurements

Microhardness measurements were performed on the sample taken from the fractured welded joint.

In table 2 are shown values of microhardness measured on sample taken from fractured welded joint, while figure 2 presents microhardness distribution diagram.

Table 2. Microhardness values of sample 1, taken from fractured welded joint.

Sample 1	HV1	Mean
HAZ	692; 675	684
HAZ/BM	564; 581; 572	572
BM	312; 339; 340; 357; 348; 355; 371; 358; 351; 332; 356	367

BM-base material of rocket case; HAZ-heat affected zone.

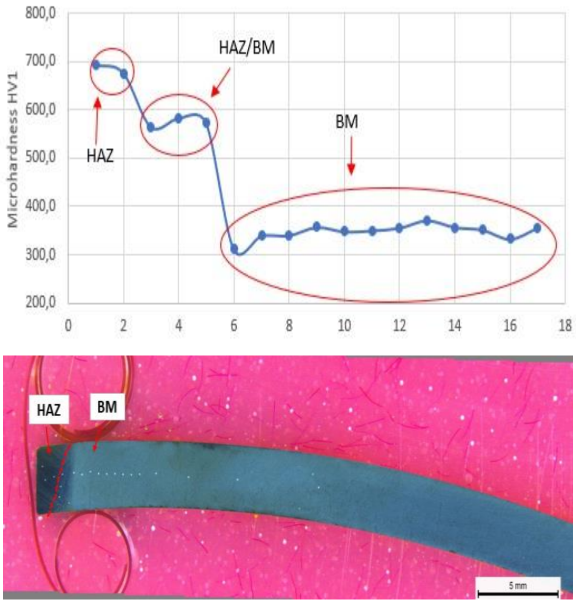


Figure 2. Microhardness distribution diagram of sample 1, taken from fractured surface.

From the results presented in table 2, there is significant difference in microhardness values between heat affected zone (HAZ) and base material (BM) of rocket case, more than 300HV1.

To try to reduce difference in microhardness between HAZ and BM, heat treatment of welded joint was performed on 500°C for 45 minutes. Heat treatment was performed on sample taken from the non-fractured welded joint.

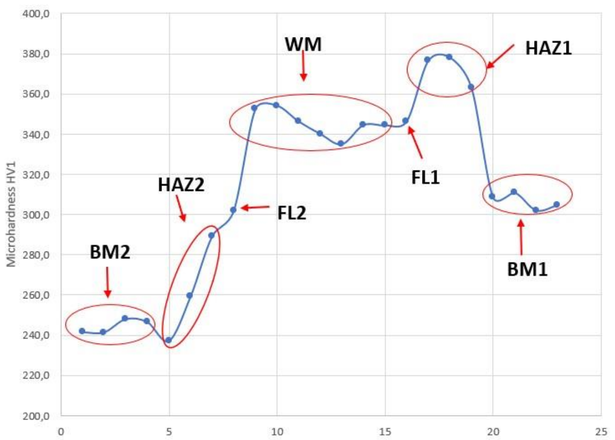
Measured microhardness values after heat treatment are shown in table 3, and microhardness distribution diagram is shown on figure 3.

Based on measured values of microhardness, it is clear that heat treatment reduced difference in microhardness between HAZ an BM of rocket case motor, from more than 300HV1 to around 70HV1.

Table 3. Microhardness values of welded joint, after heat treatment

Sample 2	HV1	Mean
BM 1	309; 311; 302; 303	306
HAZ 1	363; 378; 377	373
FL1	346	346
WM	353; 354; 346; 340; 335; 345; 344	345
FL 2	302	302
HAZ 2	237; 259; 289	262
BM 2	241; 241; 248; 247	244

BM1-base material of rocket case; HAZ-heat affected zone; FL-fusion line; WM-weld metal; BM2-base material of fins holder.



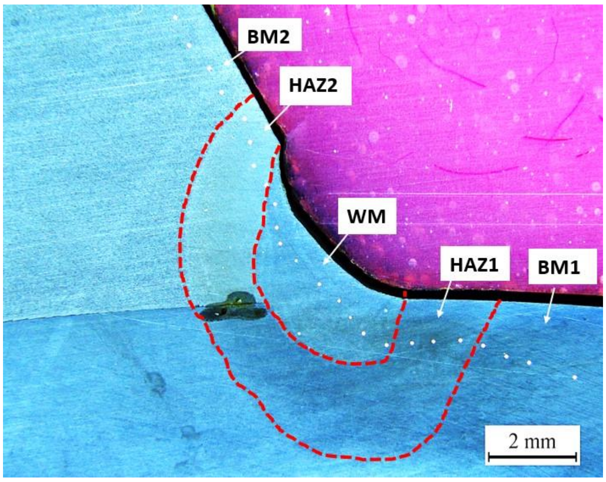


Figure 3. Microhardness distribution diagram of welded joint, after heat treatment.

3.3. Macroscopic and fractographic analysis

On figure 4 is shown picture of fractured rocket case, as well as position of samples taken for microstructure analysis (Sample 1) and hardness measurements (Sample 1 and 2), while on figure 5 is shown fractured surface.

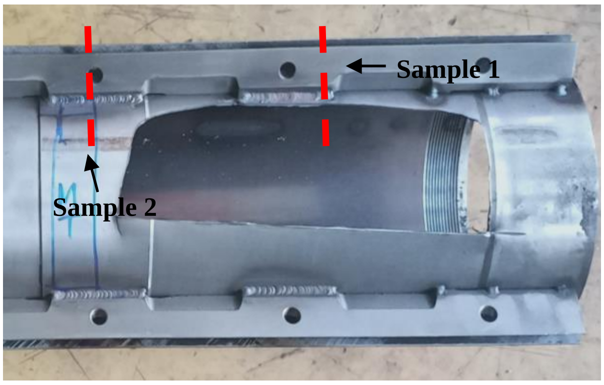


Figure 4. Part of rocket case with fractured surface.

Fracture initiation site (FIS) is on the outer surface of the rocket case, and no visible deformation was observed. However, arrow like pattern on fracture surface was observed which can provide insight on how crack propagated through material.

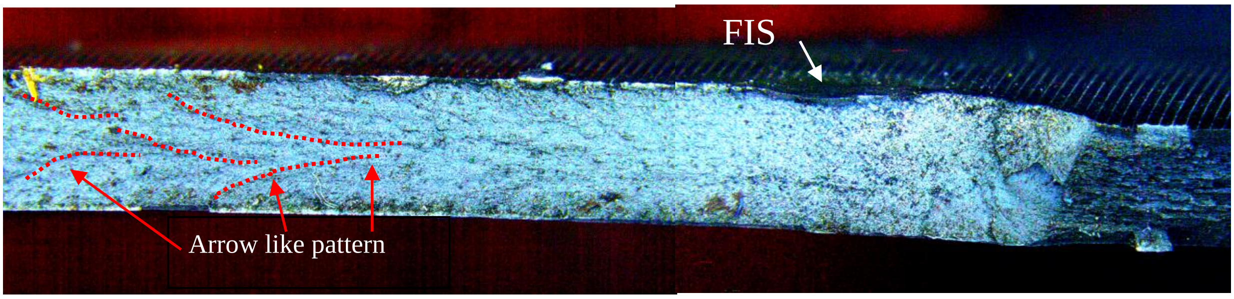


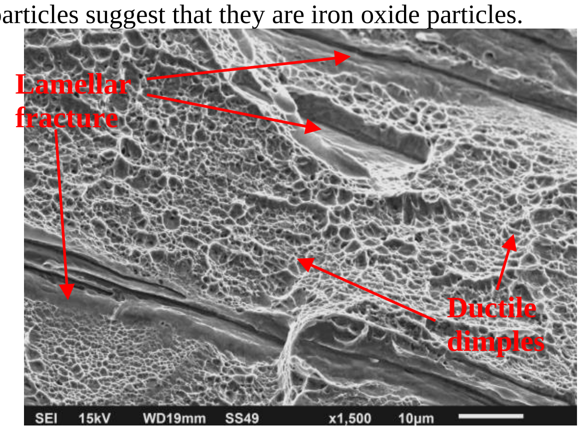
Figure 5. Macroscopic morphology of fractured surface with fracture initiation site (FIS)

To determine micromechanisam of fracture, fractured surface was analyzed in more details with scanning electron microscope. SEM analysis showed two types of fracture, figure 6a:

- Ductile fracture, with shallow and polygonal ductile dimples and
- Lamellar fracture in heat affected zone (HAZ) which is caused by stresses normal to surface of rocket case.

SEM investigation also showed high number of globular particles present in root of welded joint, figure 6b.

Semiquantitative EDS analysis, figure 7, of spherical particles showed that they contain iron, oxygen, and carbon. High concentration of iron and oxygen it these particles suggest that they are iron oxide particles.



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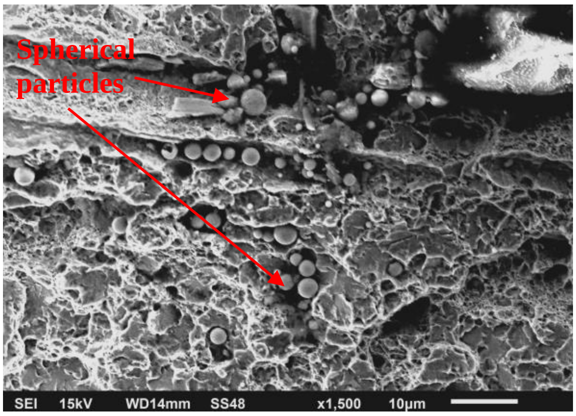

b)

Figure 6. a) Characteristic morphology of fractured surface, b) Spherical particles at root of welded joint

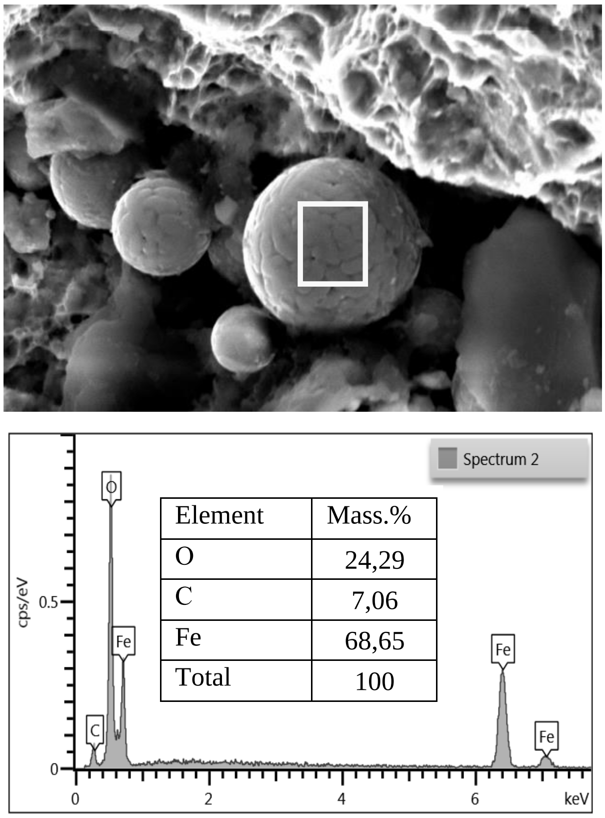

Figure 7. EDS analysis of spherical particles.

4. DISCUSION

The chemical composition of the base material of the chamber corresponds to the chemical composition of steel 42CrMo4 according to SRPS EN 10083-3 (3).

A macroscopic examination of the fracture showed that the initiation site of fracture is on the outer wall of the chamber, in the zone of the welded joint. The crack, in the initial phase of growth, extended at an angle of 45 ° to the outer surface of the rocket case. At a further stage of propagation, the crack changes direction and extends at an angle of 90 ° to the outer surface of the rocket case. No deformation of the material was observed in the vicinity of the fracture. On the fracture surface, arrow-shaped patterns were observed, which indicate the place of fracture and the direction of spread of the crack.

Fractographic examination of the fracture surface on the SEM revealed two fracture mechanisms: lamellar cleavage, i.e., stratification of the material in the direction of the thickness of the rocket case wall as well as ductile fracture with shallow low-energy pits. In the root of the welded joint, spherical inclusions based on iron and oxygen are seen. These inclusions were seen along the entire length of the root pass. Fact that these particles were found only in the root of welded joint suggest that welding process during root pass was not properly performed, aka weld metal was not shielded good enough. Nonproper shielding led to absorption of oxygen from atmosphere and formation of oxide particles.

By measuring the microhardness of the welded joint at the point of fracture and outside the fracture site, it was determined that there is a difference between the hardness of the base metal and the heat affected zone and amounts to ≈ 300 HV1. A major difference in microhardness is undesirable because it contributes to the brittleness of the welded joint. Such significant difference in microhardness can be attributed to observed microstructure. Microstructure in HAZ is martensite which have high hardness values. The microstructure of the base metal is fine grained tempered martensite.

Due to the enormous difference in hardness between the base metal and the heat affected zone, heat treatment of the sample was performed. Heat treatment resulted in a reduction in the difference in microhardness values to ≈ 70 HV1. This is attributed to decrease in residual stresses in the welded area (5).

Based on obtained results, the cause of failure of welded joint can be attributed to microstructural and microhardness variations across welded joint. Furthermore, observed oxide spherical particles in root pass indicate apparent lack of proper standard welding process.

Overall, the failure of welded joint can be attributed to all the after mentioned causes. The formation of martensite microstructure, which have high hardness, is dependent on the heat input during welding. At lower heat inputs, due to faster cooling, the formation of martensite is more expected. On the other hand, in high heat input conditions (lower cooling rates) the formation of martensite becomes less preferred, instead polygonal and ferrite structures become more dominant. Therefore, controlling the welding temperature as well as cooling rates can significantly affect the formation of different microstructures (6).

4. CONCLUSIONS

This study investigates failure of welded joint between rocket case and fins holder. Key findings include:

1. Fractographic investigation revealed mixed mode of fracture: ductile and lamellar fracture,
2. High number of oxide-based particles is seen in root pass indicating lack of proper welding procedure,
3. Microhardness distribution across welded joint showed significant difference between HAZ and BM (≈ 300 HV1) which increases brittleness of welded joint,
4. Applied heat treatment reduced difference in microhardness values between HAZ and BM,
5. Microstructure of HAZ is martensite, which is in direct correlation with heat input during welding.

Acknowledgement

This work was supported by the Ministry of Science, Technological Development and Innovations (Serbia), Contract No. 451-03-66/2024-03/200325.

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