

# Failure Investigations of Failed Micro Spline Plug Stem of SS 420 Used in Control Valve

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## ABSTRACT

*SS 420 plug component identified as a valve plug stem, which was broken while in service. It was required to study the nature and likely cause of failure. In primary phase of investigations it was anticipated that the failure may occurred due to sudden impact on the stem. The chances of failure of stem due to material defect is negligible as the part has passed all the NDT before actual installation. Hence, the detailed analysis of failure is conducted as per the requirements and presented in this paper. The chemical composition agreed with the report and the material is of SS420 grade. After the failure, the chemical composition near the crack interfaced was measured which also shows the same composition. The metallographic study is carried out with the help of SEM and OM, a specimen is removed from the crack interfaced and the study is carried out. The measured hardness of 38-42 HRC is consistent with the quenched and tempered condition. The presence of intergranular facets as observed in SEM images, the fatigue fractures in martensitic structure and in tempered structure can be attributed to ease in fracture along grain boundaries due to dislocation pile ups at grain boundaries and impurity segregations weakening the grain boundaries. It has been concluded that grain-boundary segregations and carbide precipitation, intergranular network of delta ferrite at prior austenitic grain boundaries may leads to this type of failure.*

**Keywords.** Grain boundary carbides, SS 420, Heat treatment, Failure, Valve stem

## 1. INTRODUCTION

ASTM A275 Type SS 420 plug component identified as a valve plug stem, which was broken while in service. The details site images of crack generation and failure is as shown in Fig. 1. It was required to study the nature and likely cause of failure. With reference to the problem of broken plug stem, the issue was reported on 26 May 2020, after reviewing the damaged part, material for plug stem is identified as (SS420). This plug (JP12682) is manufactured in house as per requirement of the project. In same project 5 valves are similar, but 4 plugs machined out sourcing. Plug stem broken from top side threads which is weakest portion & its observed slightly bend condition & its run out shows 0.15 to 0.17 mm.

In primary phase of investigations it was anticipated that the failure may occurred due to sudden impact on the stem. The chances of failure of stem due to material defect is negligible as the part has passed all the NDT before actual installation. Hence, the detailed analysis of failure is conducted as per the requirements.



FIGURE 1. Failure of plug stem.

### 1.1. Chemical composition of the part

The chemical composition at the interfaced of stem is measured which is as shown in Table 1.

Table 1. Chemical composition of plug stem

Element	S	Cr	Mn	Si	P	C
% Composition	0.017	12.18	0.57	0.4	0.03	0.17

The chemical composition agreed with the report and the material is of SS420 grade. After the failure, the chemical composition near the crack interfaced was measured which also shows the same composition. For the metallographic study, a specimen is removed from the crack interfaced and the chemical composition of the part was found to be consistent with the specified type 420 stainless steel. The measured hardness of 38-42 HRC is consistent with the quenched and tempered condition.

## 2. METALLOGRAPHIC ANALYSIS

A metallurgical cross section was removed from the vicinity of the crack and a metallographic sample was first mechanically wet ground using a 1500 grit silicon carbide (SiC) paper, then polished with aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) powder of 3 and 0.25 mm diameter, followed by electro etching according to ASTM E 407. After etching, the specimen was cleaned with distilled water and methanol, and then dried in air. The Fig. 2 and Fig. 3, shows the crack morphology using optical microscopy. The no etched portion clearly shows the cracks along the grain boundary and etched portion shows tempered martensite along the grains. It was observed that the surface microstructure of the plug had a tempered martensitic structure and the metallography of the cracked sample revealed highly distributed grain boundary carbides, which are both intergranular, and transgranular. Fig. 2 and Fig. 3 shows the optical micrographs showing propagation the crack along the grain boundaries

The fracture surface was cut from the valve stem, cleaned in di-hydrogen ammonium citrate and examined under a scanning electron microscope (SEM). Examination of the fracture surface are presented with following figures.

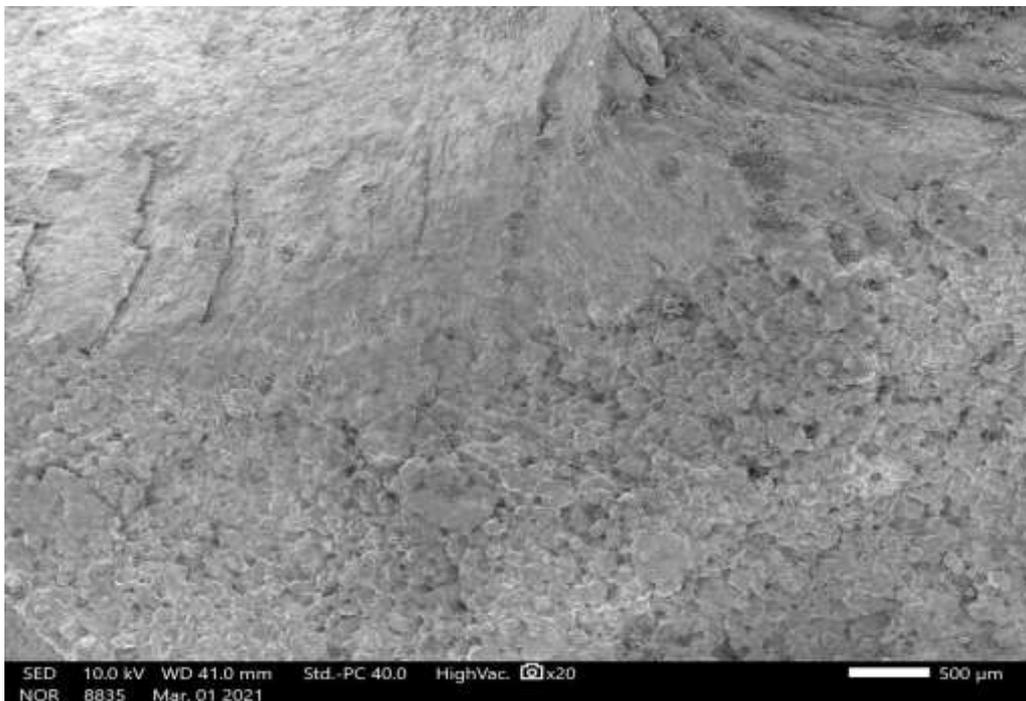


FIGURE 6. SEM image of failed crosssection showing intergranular carbides

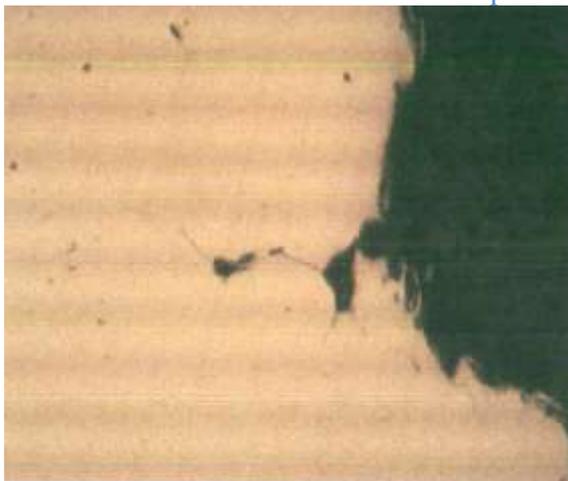


FIGURE 2. Optical micrographs showing propagation the crack along the grain boundaries.

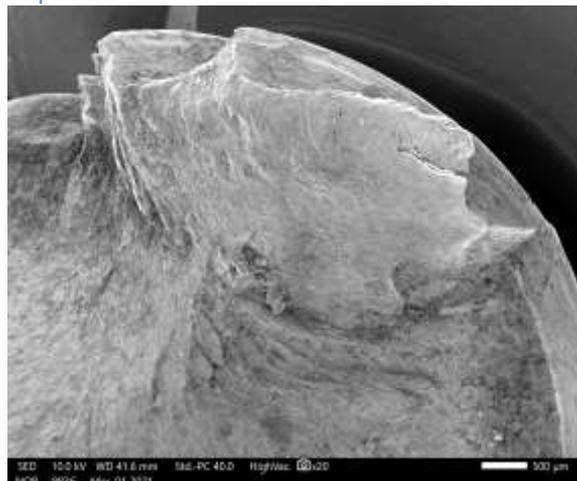


FIGURE 4. SEM image failed surface morphology showing fracture surface

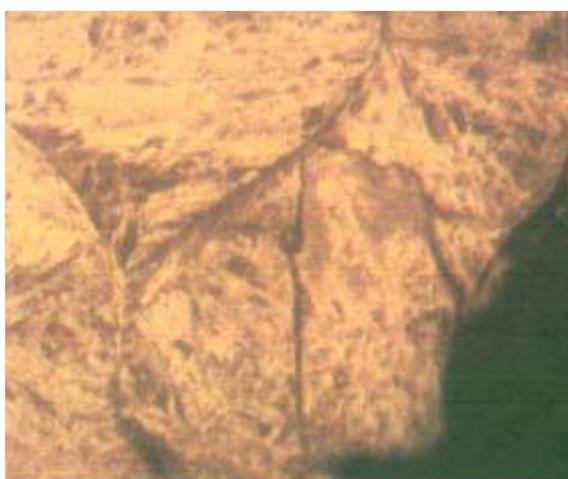


FIGURE 3. Optical micrographs showing martensitic SS 420 with intergranular cracks and grain droppings near the crack tip of the boundaries

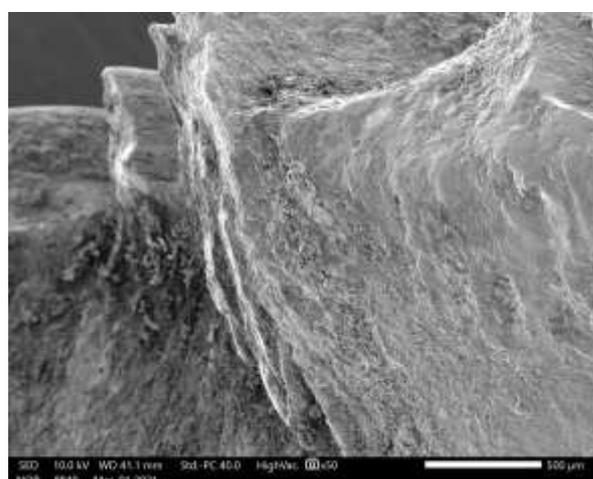
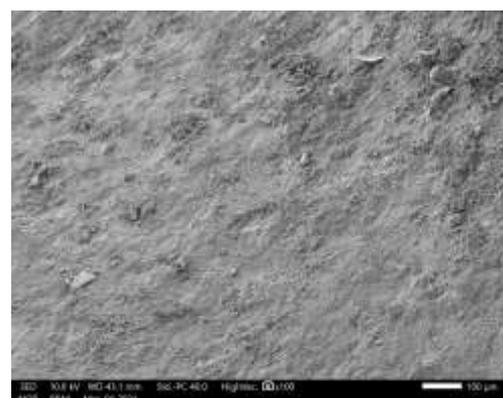
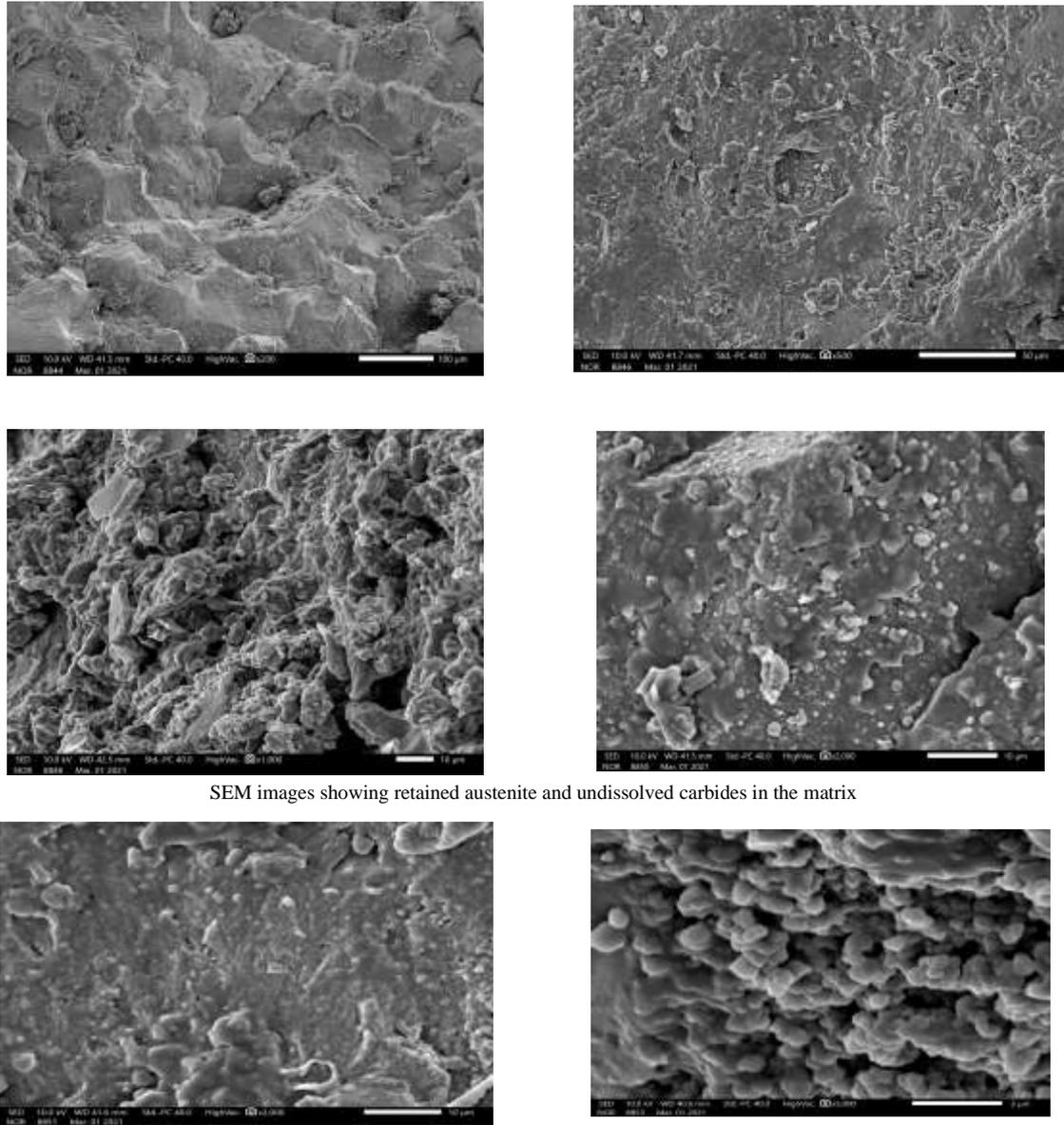


FIGURE 5. SEM image failed surface morphology showing brittle fracture surface





SEM images showing retained austenite and undissolved carbides in the matrix

SEM images showing tempered cell colonies and coarse martensite

FIGURE 6. Carbides along grain boundaries

### 3. DISCUSSIONS AND CONCLUSION

It is well known that the properties in martensitic stainless steel are strongly influenced by austenitizing and tempering treatment [1-5]. It was reported that migration of chromium atoms from the neighbours into the grain boundaries is the main cause of the carbides formation [6]. In this condition, the matrix surrounding the precipitated carbides is depleted from chromium atoms. If the chromium level in the affected area is reduced to below the critical value which is necessary for passivation, then the steel becomes sensitized to inter-granular corrosion [4, 5]. The amount of retained austenite, mechanical properties, and corrosion rate can be affected strongly by the reheating treatment even for 2 min.

Heat treatment resulted in a microstructure that consists of a tempered martensite matrix with undissolved carbides dispersed. The microstructure of AISI 420 stainless steel after quenching and tempering is usually characterized by the presence of carbides, tempered martensite and eventually retained austenite, although martensite can persist in tempering temperature. Depending on the austenitizing temperature,  $\delta$ -ferrite may also be present. Large carbides are associated with  $M7C3$ , whereas small carbides are associated with  $M23C6$ . The failure of both the components was concluded to be due to wrong tempering treatment in the temperature range of 450–600 °C that cause grain boundaries to become susceptible to embrittlement. Microstructural condition

influenced the appearance of intergranular facets during fatigue crack growth. From the various microstructures introduced, materials with martensitic structure and grain boundary embrittlement showed intergranular facets. The appearance of intergranular facets as seen in SEM images, the fatigue fractures in martensitic structure and in 535~ tempered structure can be attributed to ease in fracture along grain boundaries due to dislocation pile ups at grain boundaries and impurity segregations weakening the grain boundaries. The scanning electron micrograph in Fig. 4-5 represents the typical striation morphology of the hardened and tempered structures showed a transgranular mode of crack propagation, striation formation and ductile tearing. It has been concluded that grain-boundary segregations and carbide precipitation, intergranular network of delta ferrite at prior austenitic grain boundaries may leads to this type of failure.

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