EFFECT OF NON-METALLIC INCLUSIONS ON THE FRACTURE TOUGHNESS OF 42CrMo4 STEEL IN THE DUCTILE-BRITTLE TRANSITION RANGE

Kevin Koch[1]*, Ruben Wagner[1], Steffen Dudczig[2], Sebastian Henschel[1], Anja Weidner[1], Horst Biermann[1]
Christos G. Aneziris[2] and Lutz Krüger[1]

[1]*Institute of Materials Engineering, TU Bergakademie Freiberg, Freiberg, Germany*
[2]*Institute of Ceramics, Refractories and Composite Materials, TU Bergakademie Freiberg, Freiberg, Germany*
** Presenting Author email: kevin.koch@iwt.tu-freiberg.de*

Abstract

In this article, the effect of the volume content and distribution of non-metallic inclusions on the fracture toughness of a quenched and tempered 42CrMo4 steel is investigated. The investigations focused on the material behavior in the ductile-brittle transition range. To this end, fracture toughness tests were performed on 42CrMo4 with different inclusion characteristics. These were achieved by metal melt treatment with functional filter materials. The results showed a significant effect of both volume content and distribution of the non-metallic inclusions. The transition to brittle material behavior was accompanied by a decreasing fracture toughness as well as low scatter of the test data.

1. Introduction

Non-metallic inclusions are known to affect the material behavior of high-strength steels. Both the volume content as well as the distribution of the non-metallic inclusions have an impact on the fracture toughness. The mechanical properties are also affected by the temperature, with low temperatures favoring embrittlement due to higher risk of cleavage fracture. This can be promoted by non-metallic inclusions, which contribute an internal notch effect.

Recent studies focused on the development of functional materials for metal melt filtration, in order to reduce inclusion content and to prevent inclusion clustering in cast steels. This includes the application of both immersion as well as cast-through filters. However, there are still non-metallic inclusions present in the material even after the filter treatment. Hence, it is important to understand the effect of the remaining inclusions on the mechanical properties. The aim of this article is to investigate the effect of the volume content and the distribution of the non-metallic inclusions on the fracture toughness in the ductile-brittle transition range.

2. Experimental details

Fracture toughness tests were performed on 42CrMo4 steel with different inclusion characteristics under static loading at ambient temperature. The investigated materials were processed in a metal melt simulator. The melt treatment consisted of deoxidation as well as a combined filter treatment. For this purpose, ceramic foam filters based on carbon-bonded alumina with different coatings were used. First, a reactive filter was immersed into the metal melt. Afterwards, the melt was cast through an active filter. Three different filter configurations were utilized, see Tab. 2. C0 did not receive a filter treatment and was used as a reference. The inclusion characteristics of each material was analyzed with SEM using an automated particle analysis system FEI-ASPEX PSEM eXpress. The fracture toughness tests have been evaluated with respect to the scatter of the test data. Additionally, the fracture surfaces were analyzed after testing.

Tab. 1 – Coatings of the carbond-bonded alumina filters which were used for melt treatment.

Material	Reactive filter coating	Active filter coating
C0	-	-
C1	Carbon-bonded calcium aluminate	Flame-sprayed alumina
C2	Carbon nanotubes and alumina nanosheets	Flame-sprayed alumina

3. Results

Fracture toughness tests were carried out at ambient temperature according to ASTM E1820. The results are presented in Tab. 2. Material C0, which did not receive filter treatment, showed the highest fracture toughness. This corresponds to the low inclusion content compared to the other materials. Both C1 and C2 showed a similar volume content of non-metallic inclusions. Those were found to be mainly alumina inclusions. The decrease in fracture toughness can be attributed to the internal notch effect. However, the fracture toughness results of both materials show significant difference. Additionally, the test data of C1 shows a lower scatter compared to C2. This indicates the embrittlement of the material in the lower transition range, which can be attributed to the difference in particle distribution, see Tab. 2. The high amount of particles per area corresponds to a low distance between the non-metallic inclusions. This favored the embrittlement of the material. Due to the non-metallic inclusions being closer to each other, void coalescence can happen at lower deformation, resulting in a decrease in fracture toughness. This effect was not as significant in C2 because of the larger particle distances.

Tab. 2 – Inclusion characteristics and fracture toughness results.

Material	Mean particle diameter [µm]	Particles per area [mm^{-2}]	Volume content [10^{-3} vol%]	Fracture Toughness K_{Jc} [MPa√m]
C0	8.5	4.5	4	120 ± 15
C1	13.4	5.9	8	80 ± 5
C2	19.4	4.8	9	115 ± 10

The analysis of the fracture surfaces showed areas of both ductile as well as cleavage fracture. The lowest amount of cleavage fracture was observed in C0, while C1 showed the highest amount of cleavage fracture. Inlcusion clustering could only be observed on the fracture surface of C1, see Fig. 2. Inclusions in C0 and C2 showed higher particle distances. However, plate-like inclusions were observed in C2. These may have formed due to the reactive filter treatment.

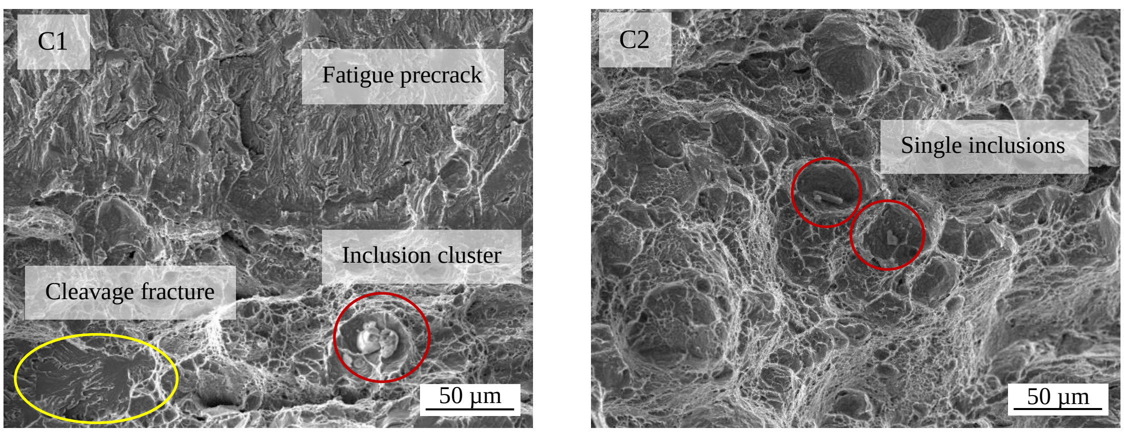

Fig. 1 – Fracture surfaces of C1 and C2 after testing.

4. Conclusions

The investigations in this article show the effect of the distribution of non-metallic inclusions on the fracture toughness behavior in 42CrMo4 steel in the ductile-brittle transition region. Both the volume content and the distribution of the non-metallic inclusions had an influence on the material behavior. The temperature-dependent embrittlement at low temperatures is promoted by the non-metallic inclusions. However, the results still have to be validated statistically.

Acknowledgements

The authors thank the German Research Foundation (DFG) for the financial support of the investigations in the Collaborative Research Center 920 - Project-ID 169148856, subprojects C01, C04 and C05.