Crash Behavior of ADI Steering Knuckles

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Within a German Egyptian Research Fund (GERF) project, prototypes of steering knuckles with varying heat treatments were produced and their crash behavior was compared to a standard type steering knuckle. Therefore, high strain rate tensile tests were performed with round bar specimens, which were extracted from steering knuckles. The ADI materials achieved tensile strength values of up to 1400 MPa and an elongation at fracture of about 1 %. Lower strength ADI qualities attained tensile strengths of about 900 MPa and 1110 MPa with elongations at fracture of about 9 % and 14 %, respectively. For comparison a standard ductile cast iron for steering knuckles achieved a tensile strength of approximately 500 MPa and an elongation at fracture of about 23 %. These results demonstrate that ADI materials may exhibit a good potential for crash loaded automotive components. The TRIP effect which leads to high strength in combination with relatively high elongation at fracture was investigated by metallographic examination and X-ray-diffraction analysis.

Keywords: Austempered Ductile Iron, ADI, TRIP, phase transformation, crash

Introduction

Within the GERF research project »Introduction of Advanced Austempered Ductile Iron (ADI) Technologies to the Egyptian Industry« prototypes of ADI steering knuckles [1, 2, 3], which denotes an automotive component containing the wheel hub and connecting it to the suspension, in three different heat treatment conditions were produced in a pilot foundry of the Department of Metal Casting at the Central Metallurgical Research and Development Institute (CMRDI). As a part of this project the potential of this ADI material under misuse and crash conditions was investigated by tensile tests with high strain rates at Fraunhofer IWM and the results were compared to a standard type steering knuckle of a German passenger car which was made of ductile cast iron. To investigate the Transformation Induced Plasticity (TRIP) effect of the ADI material under misuse and crash load conditions, additional microstructure investigations and X-ray diffraction analyses were carried out before and after the high strain rate tensile tests.

Experimental Procedure

For the investigation of ADI steering knuckles six prototypes were casted in comparable dimensions of a standard type steering knuckle of a German passenger car. All ADI steering knuckles had the same chemical composition. The chemical composition of the ADI knuckles is given in table 1 and compared to the one of the standard type steering knuckle. After casting, three different heat treatments were applied to the ADI steering knuckles. Two steering knuckles (in total six) were available for each of the three ADI heat treatment conditions, see table 2. In comparison to the standard type steering knuckle which shows a ferritic/pearlitic microstructure, see fig.1a, ADI steering knuckle #1 has a fine ausferritic matrix (acicular ferrite and 21.6 vol. % retained austenite) which is caused by the low austempering temperature of 275 °C, see fig.1b. The higher austempering temperature of 375 °C of steering knuckle #2 leads to a coarser ausferrite structure with 38.3 vol. % retained austenite, see fig.1c. A mixture of fine ausferrite with 18.4 vol. % retained austenite and colonies of proeutectoid ferrite is caused by an intercritical annealing (partial austenitization) [7] of steering knuckle #3, see fig.1d.

The content of retained austenite was determined by X-ray diffraction analysis. This method is the most common method to determine the amount of retained austenite in steels. For a polycrystalline sample, the integrated intensity from any diffraction peak is proportional to the volume fraction of that phase. The austenite fraction is determined on basis of the ratio of the austenite and ferrite diffraction peak intensities.

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Table 1: Chemical composition of standard type and ADI steering knuckles.

Alloying element	C	Si	Mn	P	S	Cu	Mo	Mg	Fe
Standard type steering knuckle	3.73	2.62	0.3	0.026	0.01	0.67	0.194	0.06	Bal.
ADI steering knuckles	3.5	2.6	0.26	0.01	0.001	0.5	0.3	0.05	Bal.

Table 2: Heat treatment of ADI steering knuckles.

Steering Knuckle	Heat Treatment		Targeted Properties
	Austenitization	Austempering	
#1	900°C - 1 hr	275°C - 1.5 hr	Excellent strength, low ductility
#2	900°C - 1 hr	375°C - 1.5 hr	High strength, improved ductility
#3	820°C - 1 hr	300°C - 1.5 hr	Lower strength and hardness good ductility and machinability

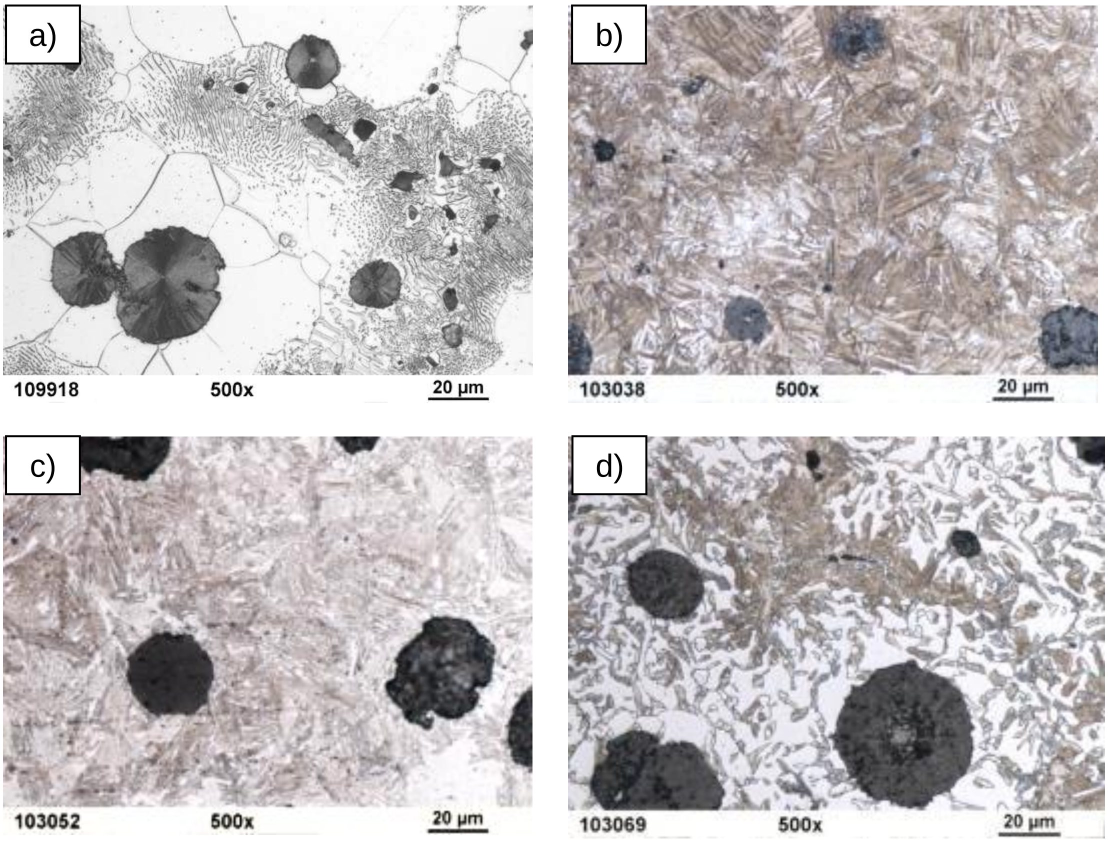

Fig.1: Microstructure of the steering knuckles: a) ferrite/pearlite and spheroidal graphite of the standard type steering knuckle, b) fine ausferrite (acicular ferrite and retained austenite) and spheroidal graphite of ADI steering knuckle #1, c) coarser ausferrite and spheroidal graphite of ADI steering knuckle #2, d) fine ausferrite, proeutectoid ferrite and spheroidal graphite of ADI steering knuckle #3

To be able to assess the material behavior under misuse and crash load conditions high strain rate tests are necessary as the mechanical properties are likely to be strain rate dependent. Therefore tensile tests were performed in a servo hydraulic testing machine at crash-like strain rates of $\dot{\varepsilon}$ = 50 s^{-1}. High speed measurement techniques were utilized in accordance with [4]. The force measurement was performed with a patent registered low vibration load cell [5] and the elongation of the gauge length of the specimens was measured by a high speed video camera [6] with a time resolution of 70.000 frames.s^{-1}. The tests were carried out at room temperature (24 ± 2 °C).

Round bar tensile specimens, see fig.2, were machined from the steering knuckles as shown in fig.3.

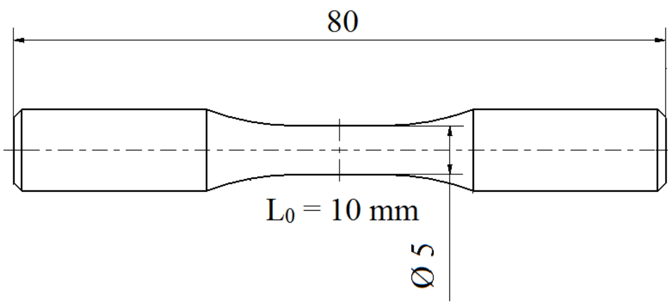

Fig.2: Geometry of the round bar specimens, which were used for the high strain rate tests.

Fig.3: Standard type steering knuckle and position of the round bar specimens.

Two ADI steering knuckles were available for each of the three heat treatment conditions. In total seven specimens have been machined from the ADI and two specimens have been machined from the standard type material for the high strain rate tensile tests.

Results and Discussion

The results of the high strain rate tensile tests are summarized in fig.4 and table 3. Here, the standard type steering knuckle shows an average tensile strength of approximately R_m = 500 MPa and an average elongation at fracture of approximately A_{10} = 23 %. The ADI material of steering knuckle #1 with a fine ausferritic microstructure (austenized at 900 °C and austempered at 275 °C) shows the highest average tensile strength of the investigated steering knuckles of R_m = 1447 MPa but the lowest elongation at fracture of A_{10} = 0.7 %. Steering knuckle #2 with a coarser ausferritic microstructure (austenitized at 900 °C and austempered at 375 °C) exhibits the best combination of tensile strength of R_m = 1110 MPa and a relatively high average elongation at fracture of 14.0 % caused by the high amount of retained austenite. The lowest tensile strength of the ADI materials was measured at steering knuckle #3 with an ausferritic / proeutectoid ferrite microstructure (intercritical annealed) with an average tensile strength of R_m = 880 MPa caused by the presence of proeutectoid ferrite. This steering knuckle showed also a relatively high elongation at fracture in the range of 8.8 - 12.2%, which is related to the effect of the presence of both proeutectoid ferrite and retained austenite..

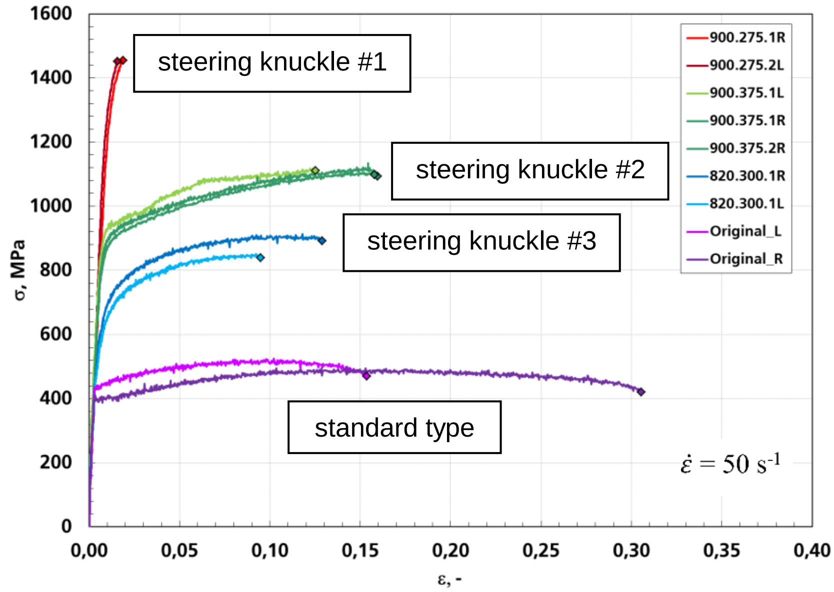

Fig.4: Results of the high strain rate tensile tests.

Table 3: Results of the high strain rate tensile tests at a strain rate of 50 s^{-1}.

Specimen	Test speed [m s^{-1}]	Strain rate [s^{-1}]	$R_{p0,2}$ [MPa]	R_m [MPa]	A_{10mm} [%]
#1, spec. 1	0.7	50	1300	1454	0.7
#1, spec. 2	0.7	50	1336	1440	0.6
average values			**1318**	**1447**	**0.7**
#2, spec. 1	0.7	50	874	1115	15.1
#2, spec. 2	0.7	50	852	1103	15.0
#2, spec. 3	0.7	50	900	1111	11.8
average values			**875**	**1110**	**14.0**
#3, spec. 1	0.7	50	620	907	12.2
#3, spec. 2	0.7	50	579	846	8.8
average values			**606**	**880**	**9.4**
standard type, spec. 1	0.7	50	395	486	30.3
standard type, spec. 2	0.7	50	436	515	15.5
average values			**416**	**501**	**22.9**

Following the high strain rate tensile tests, microstructural investigations were carried out with a light optical microscope. In comparison to the microstructure determined before the testing, see fig.1, no significant changes can be observed. Probably this is caused by the fact that the transformed martensite has a comparable etching behavior as the retained austenite. Further investigations are necessary to clarify this. By X-ray diffraction analysis, a significant reduction of the amount of retained austenite at the fracture surface of the ADI specimens was measured after the tests, see table 4. This is caused by the transformation of the metastable retained austenite under mechanical load into martensite (TRIP effect [8, 9]). This TRIP effect leads to a combination of high strain rate tensile strength and a relatively high fracture strain of the ADI material investigated. These results are in accordance with results of previous investigations under similar conditions, see [6].

Table 4: Values of retained austenite content in absolute vol. % measured by X-ray diffraction analysis before and after high strain rate tensile tests.

Steering knuckle type	Before high rate tensile test	After high rate tensile test
#1	21.6%	< 3%
#2	38.3%	3.9%
#3	18.4%	< 3%

Conclusions

1. In comparison to a standard type steering knuckle the investigated ADI steering knuckles austempered at 275°C reveal a much higher average tensile strength of R_m = 1447 MPa and a comparably low elongation at fracture A_{10mm} = 0.7 % under high strain rate test conditions (steering knuckle #1).
2. ADI material austenized at 900 °C and austempered at 375 °C (steering knuckle #2) shows a high average strength of R_m = 1110 MPa in combination with relatively high elongation at fracture of A_{10} = 14.0 %. Thus this material has a high potential for crash loaded car components also with regard to weight reduction in comparison to a standard type steering knuckle made of ductile cast iron.
3. Steering knuckles #3 partially austenitized in the intercritical temperature range at 820°C and austempered at 300°C showed lower tensile strength in the range of 846-907 MPa and a relatively high elongation in the range of 8.8-12.2%. The lower strength is due to the presence of proeutectoid ferrite, which is expected to lead to better machinability and lower production cost of the component.
4. The combination of a high strength and a relatively high elongation at fracture is caused by the TRIP effect, where retained austenite transforms into martensite under mechanical load. This reduction of retained austenite could only be verified by X-ray diffraction analysis. It could not be determined by microstructural analysis by light optical microscope.
5. Since higher deformations are recommended for suspension parts, in particular for legal reasons in context of accidents, both heat treatments used for steering knuckles #2 and #3 lead to high strength and ductility levels, which renders the resulting two ADI grades potential materials for the production of steering knuckles.

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