HIGH STRENGTH BAINITIC STEEL WELDS WITH LOW RETAINED AUSTENITE CONTENT

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Abstract

Kinetically activated bainite- KAB steels are a group of iron alloys which exhibit exceptionally rapid bainite formation kinetics at low temperatures. Traditionally this group of steels contained appreciable quantities of retained austenite in the order of 25%. The high content of retained austenite promotes very high work hardening capacity. However excessively coarse blocks of retained austenite have been encountered within the HAZ being detrimental to toughness, therefore the attention is directed towards welldable alloys with low retained austenite content.

Welds were made on a novel low temperature carbide free bainitic steel which exhibits complete formation of bainite, tantamount to a low retained austenite contents in the order of a few percent. The microstructure, hardness and impact toughness of the resulting weld and HAZs were then evaluated in the as welded and regenerated condition.

1. Introduction

Low temperature carbide free bainitic steels are known for their superior combination of mechanical properties, they are capable of achieving tensile strengths up to 2500MPa, while maintaining reasonable values of ductility and fracture toughness [1,2]. Their mechanical properties are derived from the very fine scale of bainitic ferrite plates embedded within a matrix of retained austenite. The latter undergoes a stress/strain induced transformation into martensite and gives rise to work hardening, known as the TRIP (transformation induced plasticity) effect [3]. In order to obtain fine bainitic ferrite subunits with a thickness of only 20-50 nm requires low transformation temperatures between 200 and 300°C. These unfortunately coincide with prolonged isothermal holding times, which depending on the steels composition may last from 8 hours or as long as 10 days [4]. The bainite reaction is thought to be of a displacive character, therefore the rate limiting factor is the formation of bainite nuclei [5]. This requires the paraequilibrium partitioning of carbon [6] and consequently the kinetics are slowed down exponentially with decreasing temperatures [7]. To ensure the low transformation temperatures and a carbide free bainitic microstructure substantial quantities of carbon and about 1.5% Si are present in the steels compositions [8]. The amount of carbon is rarely below 0.8 w%, resulting in high carbon equivalents.

When such steels are welded they are susceptible to cold cracking [9] due to the formation brittle martensite within the weld and reaustenitized heat affected zone (HAZ). Therefore they need to be preheated, to a temperature which usually is close to the designated temperature of bainite formation. Prolonged isothermal holding times are then applied to regenerate the bainitic microstructure within the weld and reaustenitized region [10]. As this treatments can last from several hours to days, they are performed at a slightly higher temperature, then the initial austempering. The application of rotary impacted trailed welding is also known to accelerate the regeneration [11]. It has been shown that the strength of the weld can be comparable to that of the base material as welds with tensile strengths of up to 2100 MPa (92% of the strength of base materials), have been obtained [12]. On the other hand the reaustenitized region is somewhat more prone to failure due to grain growth. It is known that larger grains form smaller fractions of bainite [13], thus requiring the heat inputs to be tightly controlled [14].

A new grade of low temperature bainitic steels with exceptionally rapid transformation kinetics at temperatures below 200°C, has been recently developed. The mechanism through which this has been achieved is by the introduction of numerous Nano scale precipitates. This precipitates develop carbon depleted zones, which upon cooling act as potential nucleation sites for the bainitic ferrite subunits. With such an approach kinetically suitable conditions for the bainite reaction are obtained at a high temperature and it thus proceeds rapidly upon cooling below Bs. By virtue of their specific trait this newly developed alloys have hence been named kinetically activated bainite (KAB) steels. In these steels fully bainitic microstructures can be easily obtained during air cooling, without the need for any isothermal holding procedures. The weldability of the new steel was subject to previous investigations, and it has been observed that the bainitic microstructure regenerates within the weld.

2. Materials and methods

The alloy was produced using master alloys and pure components, induction melted in vacuum and mold cast under a protective atmosphere of pure argon. The alloys chemical composition can be seen in table 1.

Table 1 Steel composition (in w %).

C	Si	Mn	Mo	Cr	Al	Ni	S
0.32	0,31	0,52	0,63	1	2	0,6	0,029

Certain elements have been introduced from the master alloys used or are present as unavoidable impurities. The ingot was hot forged at 1050°C, with a reduction ratio of 4, into the shape of square billets 20x70mm. Upon cooling to room temperature the newly developed steel forms a fully bainitic microstructure, comprised of fine bainitic ferrite sheaves, without any notable blocks of retained austenite, as shown in Fig. 1.

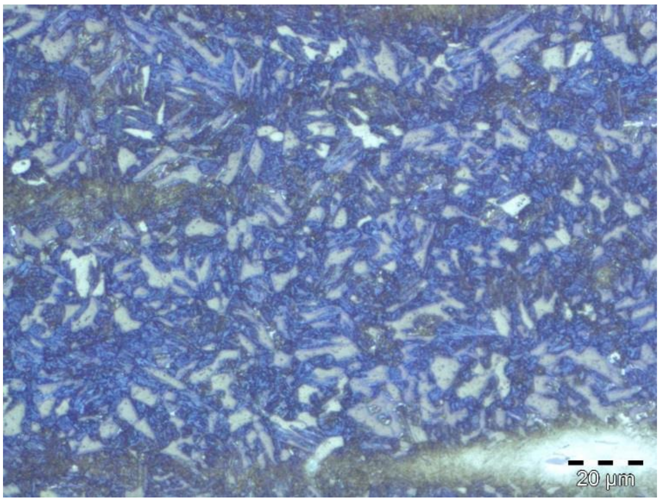

Figure 1 Initial carbide free bainitic microstructure obtained after air cooling (etched with 7% $Na_2S_2O_5$)

The microstructure is revealed by tint etching with 7% aqueous sodium-metabysulfite ($Na_2S_2O_5$). This etchant is known to respond by coloring bainitic regions blue and martensite brown, whereas retained austenite etches white or in a slight purple [18]. The absence of retained austenite is confirmed by XRD measurements which reveal only 4% retained austenite. Is is appreciable that the white etching phase is indeed delta ferrite, which is embedded in a matrix of fine carbide free lower bainite as revealed via SEM and TEM characterization. The fine bainitic matrix provides the steel with a work hardness of 46HRc.

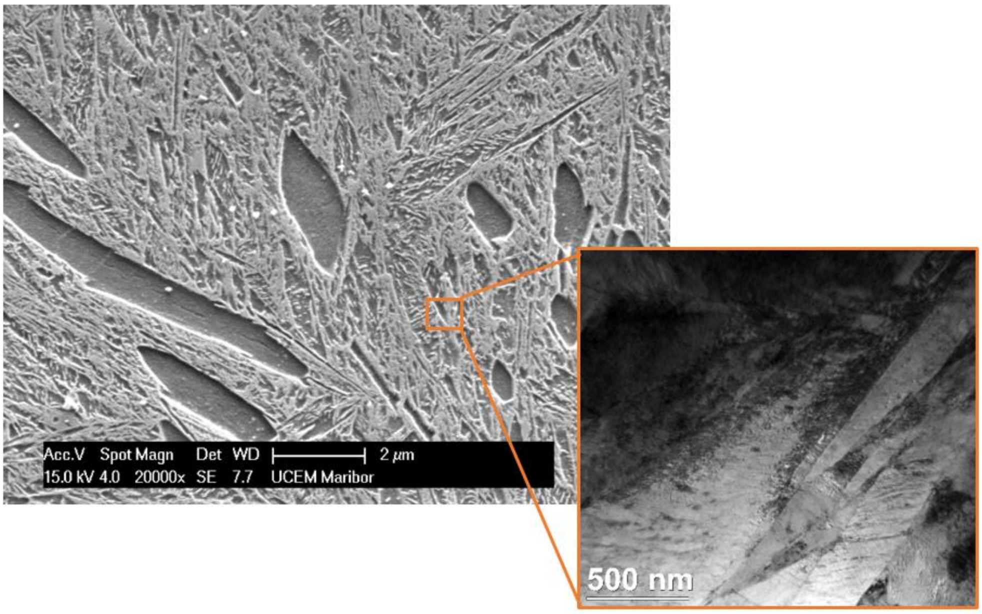

Figure 2 FESEM and TEM micrographs of initial steel microstructure.

The work hardness coresponds to an yield strenght of 1225 MPa and UTS of 1624 MPa, at a contraction of 30% and 30J KV2 as can be seen in Fig. 3

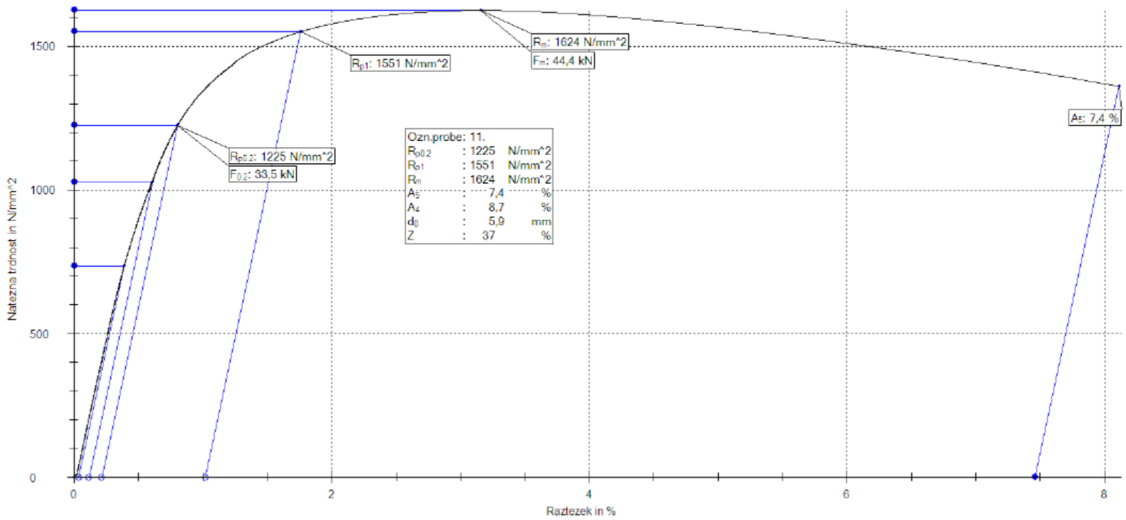

Figure 3 Mechanical properties of base material

Critical thermodynamic temperatures such as Bs, Ms, as well as the temperatures of onset and completion of austenite formation Ac_1 and Ac_3 respectively, have been determined via dilatometry and are summarized in table 2. The methods used in the calculation of the Ms temperature can be found in [15,16].

Table 2 Calculated critical thermodynamic temperatures of the newly developed KAB steel (in °C)

Ac_1	Ac_3	Bs	Ms
703	879	352	280

Welding was performed with single pass welds of too adjacent plates on a steel backing, without the use of preheating. Prior to welding an active flux was applied to increase the penetration depth.

2.2 Experimental welding and welding properties

Welds were produced using the A-Tig method, the test piece was then cut into Charpy V-notch samples, whereby the notch was positioned so that the sharp end is within the weld.

Table 3 Welding parameters

Heat input [*J/cm*]	Amp. [*A*]	Voltage [*V*]	Speed [*cm/min*]	Penetration depth [*mm*]
13630	142	16	6	cca 3

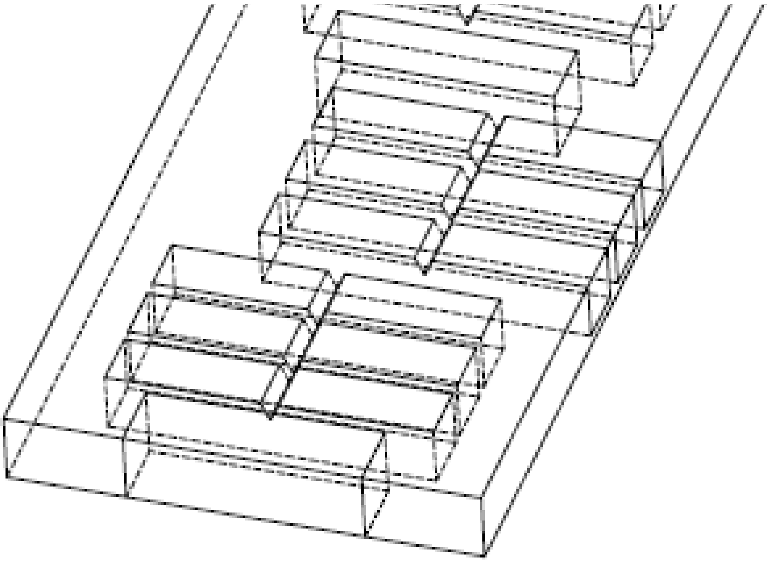

Figure 4 Welding procedure.

The welding parameters are summarized in Table 3.

2.3 Examination of test welds

Segregation in the HAZ is a common issue when welding high strength bainitic KAB steels, as it promotes coarse retained austenite as indicated in Fig 5.

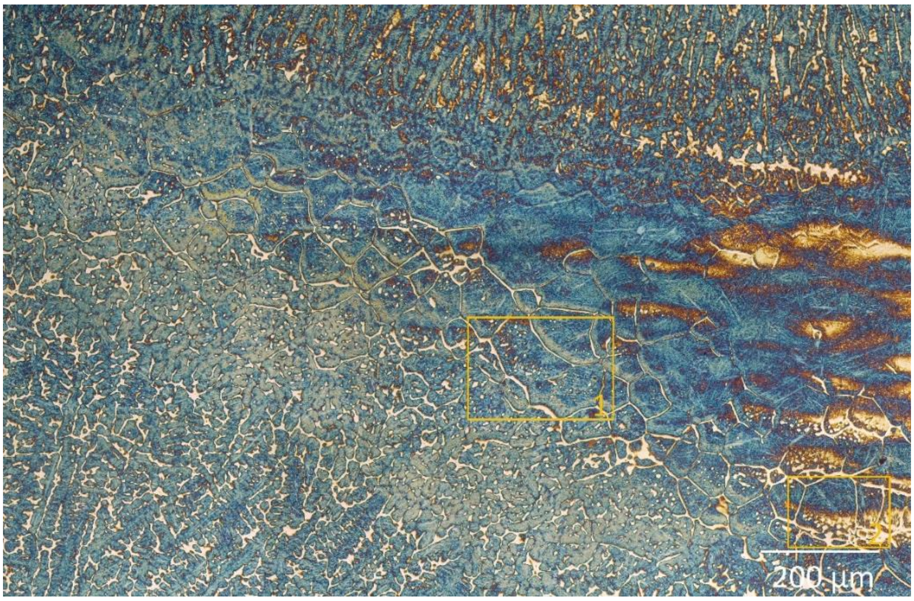

Figure 5 Characteristic microstructure of the welds and HAZs;

In the current alloy a lower concentration of alloying elements enables the full regeneration of the microstructure of the weld yielding appreciable impact toughness. The retained austenite content of the weld is comparable to the initial material and is in the order of 3% as determined via XRD measurements.

3 Results

In the as welded condition the steel exhibits a comparably low hardness

Vickers hardness HV1 was measured in a mesh across the weld and HAZ areas, as shown in the Fig. 6.

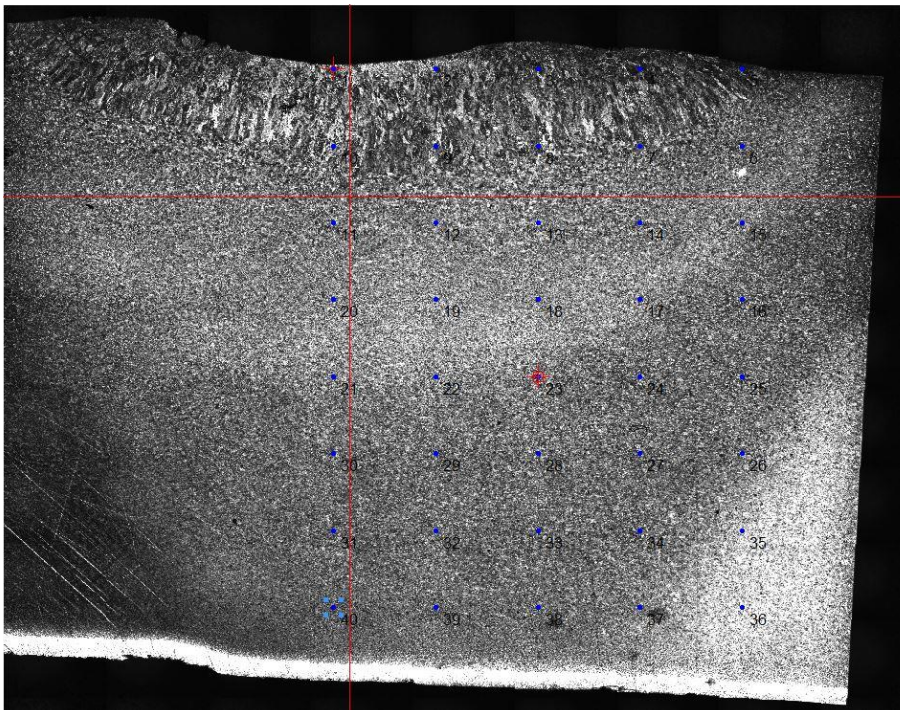

Figure 6 Locations of hardness measurments.

After welding the obtained hardness varies from 280 to nearly 400 HV1, in this condition the impact toughness of the weld and HAZs reaches values of 30 KV2.

Table 4 Hardness measurments

FIELD #	HARD. HV	FIELD #	HARD. HV	FIELD #	HARD. HV	FIELD #	HARD. HV
1	312	11	358	21	353	31	303
2	311	12	392	22	336	32	293
3	361	13	399	23	342	33	280
4	359	14	368	24	293	34	284
5	365	15	346	25	280	35	304
6	379	16	287	26	297	36	316
7	373	17	355	27	295	37	306
8	330	18	358	28	297	38	304
9	356	19	339	29	304	39	301
10	336	20	361	30	318	40	291

If the steel is reaustenitized by heating to 820°C, folloved by air cooling, the initial hardness of 46HRC is regenerated througthout the entire weld and HAZs, the impact tougthness nevertheless decreases to 22J

4 Conclusions

It would seem that an initially lower alloying content enables the completion of the bainite formation to an extent that only a very small fraction of retained austenite remains in the microstructure. This enables the steel to retain considerable values of impact tougthness also after welding.

The complete regeneration of the microstructure after reaustenitization is encouraging for the production of high strength welded structures where such a treatment is viable.

The low as welded hardness can be compensated with the use of a more alloyed of specially designed additive material. It is reasonable to assume improvements in toughness with a reduction of sulphur and impurity contents.

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