# THE ANALYSIS OF HEAT-AFFECTED-ZONE PROPERTIES OF MICROALLOYED STEELS

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Degradation rate of HAZ by welding, compared to base metal properties of four microalloyed steels had been experimentally analyzed. Steels were produced as normalized, quenched and tempered and thermomechanical control rolled. In normalized V microalloyed steel, with 0.20%C, brittle regions with martensitic microstructure in HAZ caused extremely low crack resistance of samples treated at 1350 and 950°C in simulation. Better HAZ properties are obtained with controlled rolled steels, containing less than 0.1%C. Degradation rate of properties was insignificant in HAZ of Ti+Nb and sligthly expressed for V+Nb microalloyed steel. Crack resistance of Q&T steel HAZ, evaluated by J integral is satisfactory. Microstructure is correlated with diagrams obtained by tensile and impact toughness tests.

## INTRODUCTION

Weldable microalloyed steels, produced by normalizing, had been developed for heavy duty welded structures production with minimum material consumption and costs. After several years of service in welded pressure vessels, produced of normalized V microalloyed steels, containing 0.2% C, fractures have been experienced by stable growth of cracks, initiated in the heat-affected-zone (HAZ) (1). Improved steels of similar strength level have been developed, with different alloying elements (Mo, Ti, Nb) and different procedures (quenched and tempered, thermomechanical controll rolled). The successful use of developed steels depends on the degradation rate of HAZ properties compared to base metal (BM) during welding. The occurrence of local brittle zones (LBZ) within HAZ (2) can reduce crack resistance and affect the safety of welded structure. The analysis of HAZ properties can help to proper selection of welding parameters and to understand welded structure response (3,4) to loading, enabling its service safety prediction.

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## MATERIALS AND TESTING

Four different microalloyed steels of similar strength grade have been selected for the analysis of HAZ properties and their degradation rate compared to BM during welding. The chemical composition given in Table 1, and mechanical properties listed in Table 2. Normalized steel A, with 0.2% C, is V microalloyed, thermomechanical control rolled steels B and C, with 0.1% C, are V+Nb and Ti+Nb microalloyed, and quenched and tempered steel D is Mo+Nb microalloyed. Crack and fracture problems are found in steel A welded structures (1). Steel D is developed to replace steel A and the most promising steels B and C belong to new generation.

TABLE 1 - Steel chemical composition

| Steel | C | Si | Mn | P | S | Al | Cu | Nb | Cr | Ni | Mo | Ti | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.20 | 0.51 | 1.42 | 0.020 | 0.010 | 0.018 | 0.035 |  | 0.018 | 0.574 | 0.017 |  | 0.180 |
| B | 0.07 | 0.43 | 1.43 | 0.012 | 0.012 | 0.037 | 0.043 | 0.031 | 0.018 |  | 0.017 |  | 0.087 |
| C | 0.08 | 0.20 | 1.12 | 0.027 | 0.011 | 0.033 | 0.065 | 0.026 | 0.065 | 0.019 | 0.010 | 0.017 |  |
| D | 0.06 | 0.32 | 1.01 | 0.014 | 0.004 |  | 0.30 | 0.060 | 0.017 | 0.150 | 0.230 |  |  |

TABLE 2 - Mechanical properties of tested steels

| Steel | Yield strength, MPa | Tensile strength, MPa | Elongation, % | Impact toughness, J | Hardness, $HV_5$ |
|---|---|---|---|---|---|
| A | 490 | 720 | 17.0 | 130.2 | 262 |
| B | 460 | 596 | 32.7 | 142.7 | 204 |
| C | 430 | 520 | 34.6 | 228.9 | 199 |
| D | 490 | 611 | 27.0 | 203.5 | 203 |

Steel D welded joints and HAZ crack properties had been evaluated by J integral and final stretch zone size on precracked Charpy size specimens, with crack tip positioned in WM different HAZ regions (3, 4). The heat-affected-zones of other three steels had been analyzed by simulation on Smitweld LS1402 device. The samples, 11x11x55 mm, had been exposed to different temperatures (1350°C, 1100°C, 950°C, 850°C) for 15 s as cooling time $\Delta t_{8/5}$. The sample central part, about 20 mm long, had been affected by heat during simulation and served as measuring region for hardness test ($HV_5$), tensile test ($\phi$ 4.5 mm round specimen) and Charpy V instrumented impact test. Microstructures of HAZ regions had been analyzed by light microscopy and the correspondence to tensile and impact toughness tests diagrams established.

## RESULTS AND ANALYSIS

The results of simulated samples testing are listed in Table 3. Figures 1 and 2 represent microstructures and corresponding diagrams of tensile and instrumented impact tests for steels A and C, selected as typical regarding HAZ properties.

High hardness of steel A corresponds to 0.2% C content. Increasing hardness and tensile strength of simulated samples are expressed for this steel and this can be explained by martensitic microstructures in samples heated to 1350°C and 950°C (Fig. 1). Tensile properties and low impact toughness indicate brittle behaviour at 1350°C, but also at 950°C, when the yield strength (950 MPa) is lower compared to tensile strength (1189 MPa).

TABLE 3 - Test results of simulated samples

| Steel samples | Simulation temperature, °C | Yield strength, MPa | Tensile strength, MPa | Elongation, % | Impact toughness J | Hardness, HV5 |
|---|---|---|---|---|---|---|
| A1 | 1350 | 1101 | 1101 | - | 7.7 | 480 |
| A2 | 1150 | 717 | 1036 | 18.0 | 46.2 | 353 |
| A3 | 950 | 950 | 1189 | 12.6 | 10.6 | 418 |
| A4 | 850 | 636 | 936 | 11.8 | 31.6 | 338 |
| B1 | 1350 | 629 | 726 | 18.0 | 48.0 | 287 |
| B2 | 1150 | 464 | 631 | 28.0 | 96.3 | 252 |
| B3 | 950 | 546 | 675 | 21.7 | 60.7 | 265 |
| B4 | 850 | 472 | 672 | 31.3 | 165.9 | 232 |
| C1 | 1350 | 486 | 601 | 26.0 | 172.2 | 236 |
| C2 | 1150 | 452 | 557 | 32.3 | 197.8 | 225 |
| C3 | 950 | 408 | 549 | 35.7 | 203.7 | 210 |
| C4 | 850 | 377 | 565 | 40.0 | 184.8 | 212 |

Degradation rate in HAZ of steel C with 0.074%C content, Ti+Nb micro-alloyed, is insignificant. Maximum hardness of simulated samples reaches 236 $HV_5$, that is only slightly higher compare to base metal (199HV). Beinitic microstructure (Fig. 2) at higher simulation temperature does not produce significant changes of basic steel properties and one can expect high crack resistance of steel C welded joints and HAZ. Slight decrease of yield strength (377 MPa) at 850°C can indicate soft interlayer behaviour, but increasing tensile strength (565 MPa) and very high elongation (40%), can be a guaranty for proper behaviour of welded structure.The properties of steel B simulated samples with 0.07% C and V+Nb microalloyed are acceptable. As in the case of steel A, the temperatures of 1350°C and 950°C are critical due to high hardness and increased strength. This is in accordance with coarse beinitic structures found at this temperature.

Convenient beinitic microstructure in HAZ of steel D in critical region close to fusion line can be connected to low C content (3). Analyzed fracture mechanics parameters of different HAZ regions enable to conclude that welded joint of this steel can be satisfactory produced by properly selected welding regime.

## CONCLUSION

Experimental analysis has confirmed that thermomechanical control rolled steel with low C content, Ti+Nb microalloyed, can be recommended for welded structures due to insignificant degradation of properties in HAZ compared to base metal. It is to be noticed that the tensile properties are lower compared to the other tested steels, but considering welded joints and welded structures as a whole, and taking account producing costs, this steel can be evaluated as superior. However, welded structures of steel B and D can be evaluated as satisfactory too, under the condition of strictly controlled welding procedure. The welding of steel A is accompanied by significant difficulties with expressed degradation rate of HAZ compared to BM. Two regions of HAZ in steel A exhibited extremely high degradation rate of BM and low crack resistance can be expected in these regions, explaining service crack occurrence in welded joints (1). Obtained results show that this steel has to be welded with precaution and carefully selected welding parameters in order to reduce the effect of inconvenient microstructure.

## REFERENCES

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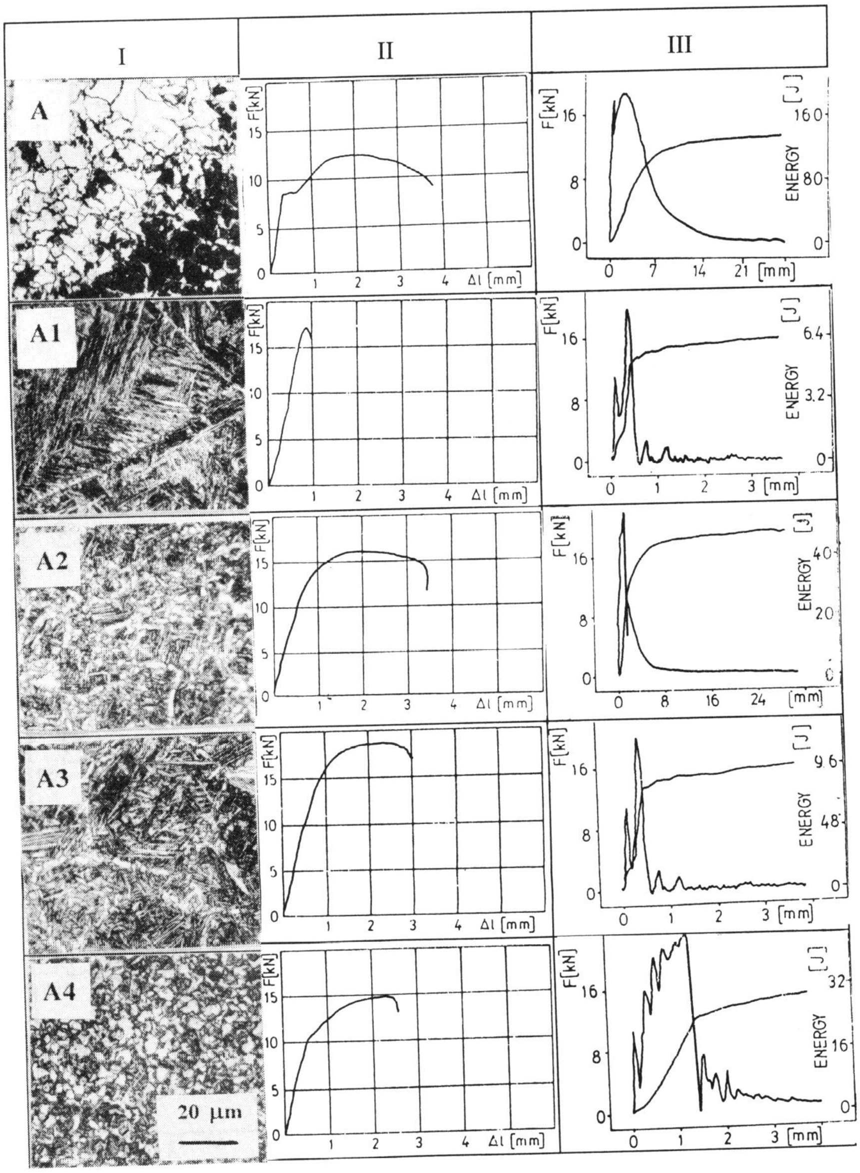

Figure 1 Microstructure (I), tensile test diagrams (II) and instrumented impact test diagrams (III) for base metal steel A and samples simulated at 1350°C (1) ,1100°C (2), 950°C (3) and 850°C (4)

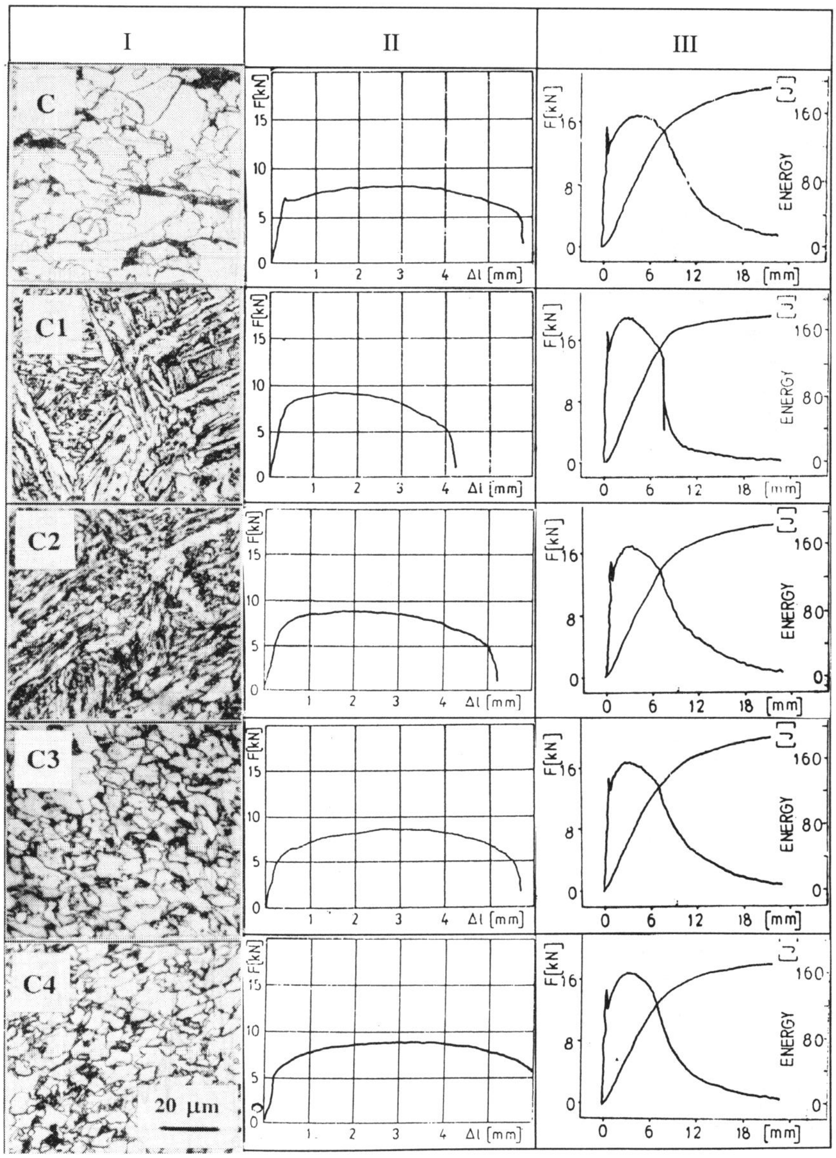

Figure 2 Microstructure (I), tensile test diagram (II) and instrumented impact test diagrams (III) for base steel C samples simulated at 1350°C(1) ,1100°C(2), 950°C (3) and 850°C (4)