THE POSSIBILITY OF EVALUATING THE YIELD STRENGTH THROUGH INDENTATION

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Abstract

The subject of the research is study of an elastic-plastic behavior of the materials, S355N steel and Domex700MC steel, which are used in welded construction parts of car bodies, the Domex700MC steel is used with the intention of decreasing the weight of the parts. The solved problem is to determine the local static parameters of the steels without the possibility to use the standard mechanical testing. In order to assess the strength decrease, the critical area was experimentally simulated. The main aim of the paper is to ascertain strength differences in the heat affected areas originating as a result of welding. As the main tool for the assessment of the elastic-plastic response, the methodology based on an instrumented penetration test with the use of a cylindrical indenter was chosen. For validation of the used method, the standard tensile test was performed. The aim of the work is to state optimal methods for determining of yield strength and to find a changes tendency in these areas. The comparison these steels revealed different changes due to welding process. The substantial decrease of the yield strength of Domex700MC was observed on contrary to stable, or partially increased, yield strength of the S355N steel. Structural analyses revealed a different material response of the evaluated steels, according to a different hardness in the heat affected zone.

Keywords: Mechanical properties, indentation method, microstructures, hardness, tensile test

1. INTRODUCTION

The demands made by the present manufacturers, especially by those from the vehicle industry, on construction material qualities are the impetus to the enhancement of the standard construction materials.

The materials have to comply with many, very often contradictory, qualities. On one hand, it is a higher yield stress and strength, and, on the other hand, sufficient tensibility and weldability [1].

In order to provide the maximum safety for the passengers simultaneously with the lowering operational weight of vehicles, the advanced high strength steels (HSS, AHSS) have been recently used in the production of car bodies. These groups of steels bring specific combinations of mechanical parameters, abilities of dynamic reinforcement together with keeping tendency to ductile fracture in a wide range of working temperatures but also specific requirements for technological operations - primarily for forming and welding [2].

These high demands are also met by the micro-alloyed steels which contain a defined number of alloying elements which create strengthening precipitates. The typical manufacturing technology of the steels is a controlled rolling in the area of austenite during temperatures around 1000 °C and subsequent moulding at lower temperatures (around 800 °C) [3]. DOMEX 700MC is representative of steel used for the production of safety components in the automotive industry. The welded joints are distinctive by the heat affected zone which is characterized by a different structure and attributes. In the case of common steels, in which the size of their grain together with precipitating phases layout do not have such a big influence on the resulting attributes. A very important problem comes in the case of micro-alloyed steels, which get their specific attributes thanks to the above mentioned factors [4]. The aim of the work was to validate suitable methodology for direct evaluation of mentioned structural and strength heterogeneity in these zones. As the main tool for assessing the elastic-plastic response, the methodology based on the instrumented indentation test which uses a cylindrical indenter was chosen [5]. The tensile test was chosen as a reference method.

4. EXPERIMENTAL PROCEDURE

The samples for the experiment were chosen from fine-grained steel S355N and high strength steel DOMEX 700MC, both as a prospective material for lowered weight frame for application in transport means [4]. The chemical composition of both steels is stated in **Table 1**. Experimental weld joints were prepared according the common requirements for both steels. Welding technology has been selected manual metal arc welding.

Table 1 The composition of [wt. %]

DOMEX 700MC	**C**	**Mn**	**Si**	**P**	**S**
	0.12	2.1	0.1	0.025	0.01
	V	**Al**	**Ti**	**B**	
	0.2	0.015	0.15	0.004	
S355N	**C**	**Mn**	**Si**	**P**	**S**
	0.22	1.6	0.55	0.03	0.03

Basic evaluation of induced mechanical changes was based on the hardness measurement, the elastic-plastic response was evaluated by indentation test both parent materials compared to heat affected zone. Validation of suggested methodology for yield strength assessment was based on experimental creation of heat affected zone. Samples (dimensions in **Fig. 1**) were submitted to temper treatment as a simulation of a welding temper influence.

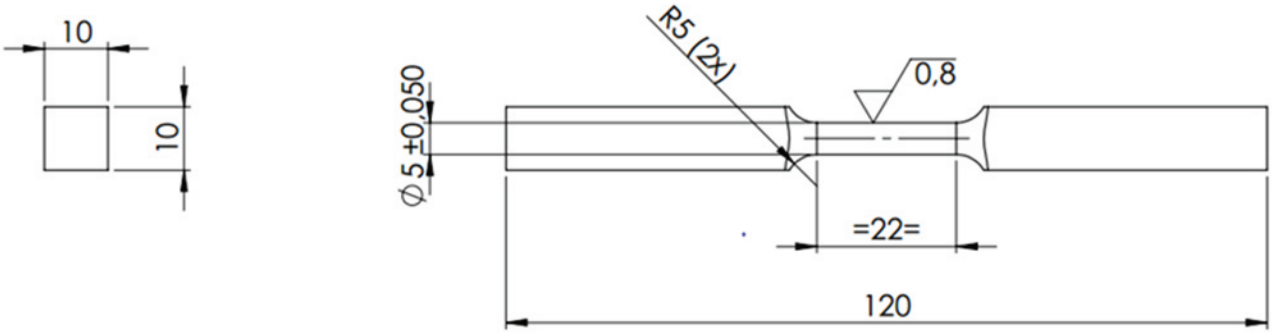


Fig. 1 The shape of the sample

During welding, different thermal zones occurred and a different structural changes as a consequence of welding cycle with entire wide of heat affected zone 2.5 mm for S355N a 3.5 mm for Domex 700MC. Cylindrical indenter 1.2 mm in diameter was used for performed indentation test. In order to monitor the strength loss of both materials by suggested methodology, the temperature of 1000°C in furnace was chosen as a representative level of thermal influence for sublayer. This attitude enables uniaxial testing of simulated affected zone with homogenous microstructure in tested deformation zone. Resulting values of strength loss evaluated by hardness measurement are stated in the **Table 2**.

Table 2 Hardness differences (HV10) induced by experimental welding vs. experimental temper treatment:

- SA/SU/SO - S355N (experimental temper treatment affected/ unaffected parent material /heat affected zone of original weld)
- DA/DU - DOMEX 700MC (affected/unaffected/ heat affected zone of original weld)

S355N					
SA-01	162	**SU-01**	182	**SO-01**	173
SA-02	160	**SU-02**	182	**SO-02**	178
SA-03	162	**SU-03**	184	**SO-03**	193
SA-04	163	**SU-04**	182	**SO-04**	182
SA-05	160	**SU-05**	184	**SO-05**	180
Average value	**161**		**183**		**181**
DOMEX 700MC					
DA-01	179	**DU-01**	288	**DO-01**	230
DA-02	180	**DU-02**	290	**DO-02**	240
DA-03	178	**DU-03**	293	**DO-03**	255
DA-04	182	**DU-04**	288	**DO-04**	262
DA-05	180	**DU-05**	291	**DO-05**	258
Average value	**180**		**290**		**249**

4.1. Structural analyses of heat induced changes

Domex AHSS offers superior strength, high impact toughness, good weldability, formability and cutting properties and alloys to reduce the weight without sacrificing strength. The chemical analysis, consisting of low levels of carbon and manganese has precise addition of grain refiners such as niobium, titanium or vanadium. This makes Domex Steels the most competitive alternative for cold formed and welded products. Domex 700MC has obtained its mechanical properties by a quenching process.

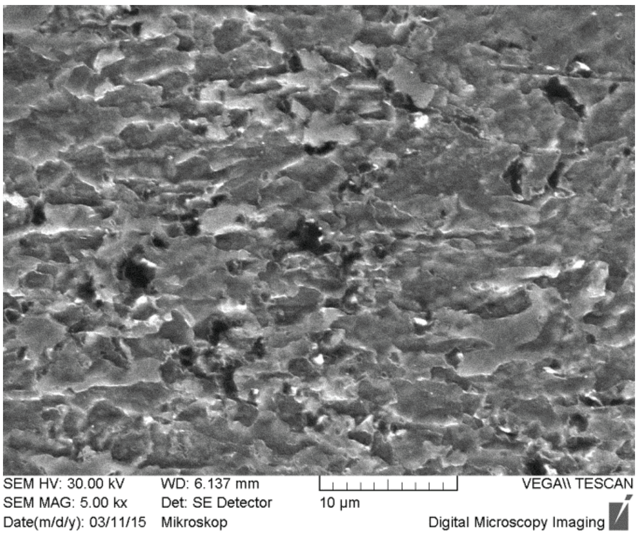


Fig. 2 Microstructure of unaffected Domex steel

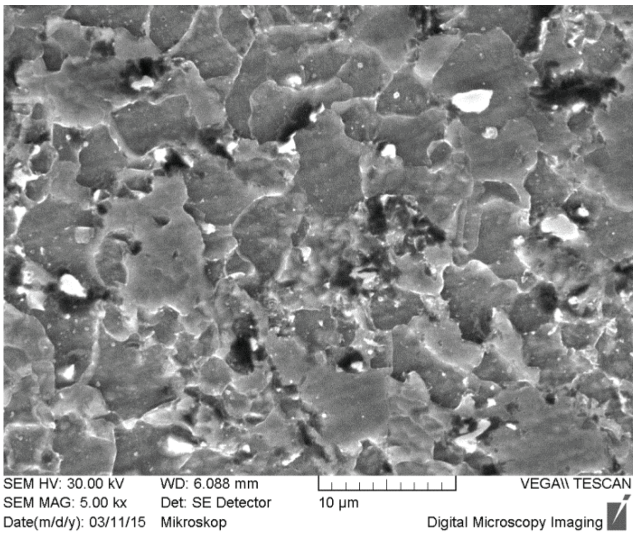
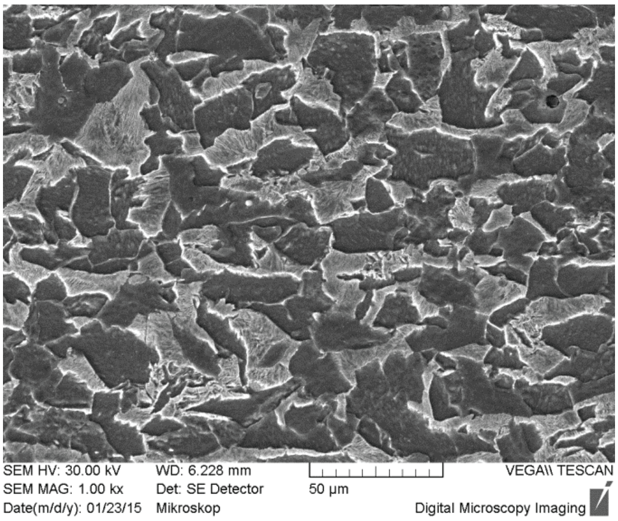


Fig. 3 Microstructure of Domex steel-heat affected zone

The **Fig. 2** shows the microstructure in natural form with visible cold-forming effect. Irregular, locally rough carbide precipitation was observed in heat affected zone of butt weld performed by shielded metal arc welding. Additionally, the recrystallization of primary deformed grains and mild coarsening were observed (**Fig. 3**). All of these processes are generally source of the impairment of strength and impact toughness. The unaffected ferritic-pearlitic microstructure of S355N steel is pictured in **Fig. 4**. Contrary to the Domex 700MC, no substantial softening processes were observed in heat affected zone, except of grain coarsening effect in area adjacent to the fusion zone. The desk shape carbides forming, partially bainitic transformation suppressed the grain coarsening effect and even induced the local increasing of hardness (**Table 2**).



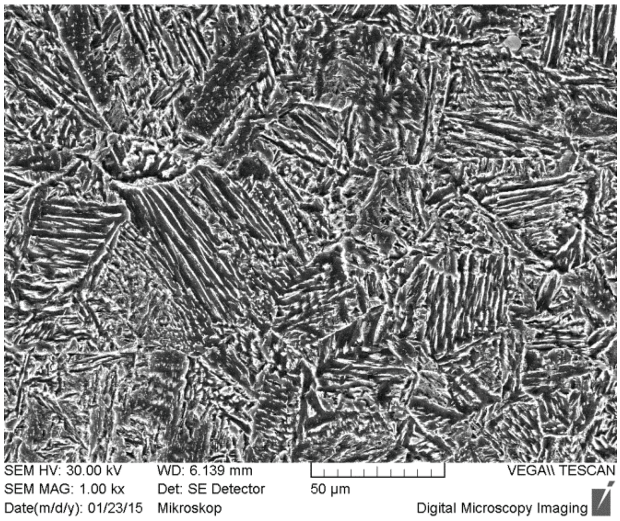


Fig. 4 Microstructure of unaffected S355N steel **Fig. 5** Microstructure of S355N steel-heat affected zone

4.2. Used indentation method

Universal hardness tester Zwick ZHU2.5 was used for the experiment. The load on the cylindrical indenter was elected 2.5 kN. According to Hecky´s hypothesis about behaviour of the material during extrusion of a cylindrical indenter, the ratio of measured instrumented yield force to relative yield force in shear is 2.57 [1].

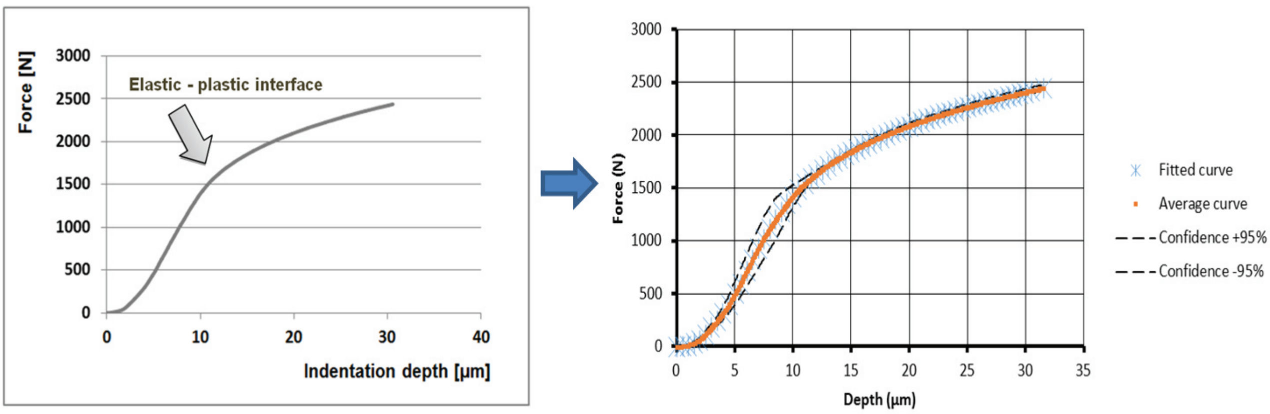


Fig. 6 Process of indentation method **(a)**, generated values of the the yield strength **(b)**

Because of high number of measurement data there was used Visual Basic macro in Microsoft Excel 2010. This macro averaged data from all measurement specimens and also detected indentation Yield Strength (YS). The averaged curve is also fitted by user defined scale and on this fitted curve is detected YS. Drop of directive is decisive for definition of YS, in this case was defined on 10per. It is shown in **Fig. 6b)**. The process of evaluating the shear yield strength is based on the method of least squares.

Table 3 Indentation Method - indentation shear yield strength vs. tensile yield strength

Sample	Indentation Method [MPa]	Yield Strength - tensile test [MPa]	Sample	Indentation Method [MPa]	Yield Strength - tensile test [MPa]
SU-01	370	352	**SA-01**	340	333
SU-02	355	335	**SA-02**	330	320
SU-03	350	328	**SA-03**	315	318
SU-04	355	330	**SA-04**	325	323
SU-05	372	355	**SA-05**	333	335
AVERAGE	**360**	**340**		**328**	**326**
Sample	**Indentation Method [MPa]**	**Yield Strength - tensile test [MPa]**	**Sample**	**Indentation Method [MPa]**	**Yield Strength - tensile test [MPa]**
DU-01	720	690	**DA-01**	330	325
DU-02	725	710	**DA-02**	325	324
DU-03	695	705	**DA-03**	320	330
DU-04	705	710	**DA-04**	335	335
DU-05	710	690	**DA-05**	330	333
AVERAGE	**711**	**701**		**328**	**329**

3. CONCLUSION

Evaluation of elastic-plastic response in heterogeneous heat affected zone was study. For the experiment, two steels were used - structural steel S355N and high strength steel DOMEX 700MC in order to discover the intensity of the strength changes. The experimental welding joints were prepared. For validation of used methodology of yield strength assessment both steels were subject to simulation of heat load of 1000°C and evaluated by standard tensile test. Comparison of welding vs. simulated temper exploitation was performed by hardness measurement and structural analyses.

The main aim of the experimental work was to assess the yield strength with the help of the indentation method. The tool for the method was the cylindrical indenter. The acquired characteristic curve was converted according to the relationships for tension in material into the shear yield strength. For the purpose of assessment, the least square methods was used and the elastic-plastic borderline of the tested material was evaluated.

It was found that the tested methodology is applicable for evaluation of local mechanical heterogeneity such as heat affected zone of welds. The difference of YS originating between the results obtained through different methods (indentation test vs. tensile test) can be caused by:

- A local heterogeneity of the examined sample
- Presence sublayers with different strength in the heat affected zone

The main advantages of the indentation method are as follows:

- The assessment of changing mechanical attributes resulting from welding
- Direct method for evaluation of shear yield strength
- The complicated sample preparation is not necessary

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