Influence of the welding proces on the martensitic and dual phase high strenght steels

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The subject of the study are martensitic 22MnB5 steel and dual phase steel with the ferrite-martensitic structure, which are used in the automotive industry. The main purpose of the performed analyses is a study of strength differences in heat affected zones of the spot welding. For the needs of the strength decrease assessment, the critical layer of the heat affected area was experimentally simulated by different thermal influence procedures. The aim of the work is to determine the most suitable methodology for evaluating the local changes of the elastic-plastic material response. The yield strength and the deformation hardening are required constructions of safety carbody parts.

Key words: Martensitic steel, dual phase steel, heat affected zones, yield strength, weld-joint fractures, indentation

1 Introduction

In order to provide the maximum safety for passengers simultaneously with lowering operational weight of vehicles, advanced high strength steels (AHSS) are recently used during 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 [1, 2].

Dual-phase steels (DP) are the result of such a mechano-thermal processing, during which cold-rolled sheet metal is rapidly heated till the intercritical area of austenite and ferrite with consecutive controlled cooling, during which the remaining part of austenite is transformed into martensite (usually 5-20%). The ratio of these two phases is the key factor for both strength and plasticity [3]. If almost all of the austenite is transformed into martensite, high strength martensitic steel is formed. It is one of the widely used AHSS during cold or hot forming. Mostly homogenous martensitic matrix is sometimes supplemented by a certain part of lower bainite and, where appropriate, by free ferrite or residual austenite. Martensitic steels are used for the safety sections in the automotive industry because of their highest tensile strength up to 1800 MPa and the tendency to the ductile fracture mode even during high speed loading [4, 5].

The employing of high strength steels includes two main areas of problems. On of them is the research towards technological parameters of welding, which should suppress the undesirable strength loss inside the critical layers of joints. The other area is the necessity of registering the actually induced structural layer changes, which could influence the strength and the plasticity of the welded joints. The problem of the above stated high strength steels lies mostly in the tendency to a local loss of the distributive strengthening together with the undesirable tempering of the martensitic element, obtained through the specific technological procedures of semi-finished product processing.

Aim of the presented work is to find the new way for the evaluation of the softening (strengthening) process intensity due to applied spot welding technology. The comparative tensile tests were used for experimental evaluation of used methodology.

2 The Experimental Assessment of the Heat Loading Influence

The samples for experimental examination (chemical composition in the Tab. 1) were prepared from the 22MnB5 steel and dual phase steel.

In practice, these materials are jointed by resistance spot welding. But the high initial material strength and the presence of the above mentioned surface treatment, especially the Al-Si layer by 22MnB5 steel, bring specific conditions for acquiring a first-rate joint. Tests proved that it is primarily the thickness of the silicon enriched interlayer on the border of the base material which is limiting for weldability. With the change of the interlayer silicone rich sublayers thickness, gradual iron saturation appears. Then, this effect seems to be substantial for weldability [6, 7].

***Tab. 1** The basic composition of martensitic steel material [wt%]*

Sample	*C*	*Mn*	*Si*	*P*	*S*	*Cr*	*Ni*	*Cu*	*Al*	*Ti*	*B*
Martensitic	*0.25*	*1.25*	*0.25*	*0.02*	*0.002*	*0.19*	*0.01*	*0.02*	*0.043*	*0.04*	*0.0035*
DP steel	*0.16*	*1.98*	*0.21*	*0.02*	*0.02*	*0.21*	*0.01*	*0.01*	*0.01*	*0.02*	

3 The simulated heat loading

The assessment of the elastic-plastic behaviour of the strength loss layers was based on the simulated heat loading of the samples, which were tested by the standard tensile tests. The shape of the samples was adapted in order to enable the heat loading simulation process (Fig. 1). The samples were cut from flat carbody parts intended for spot welds.

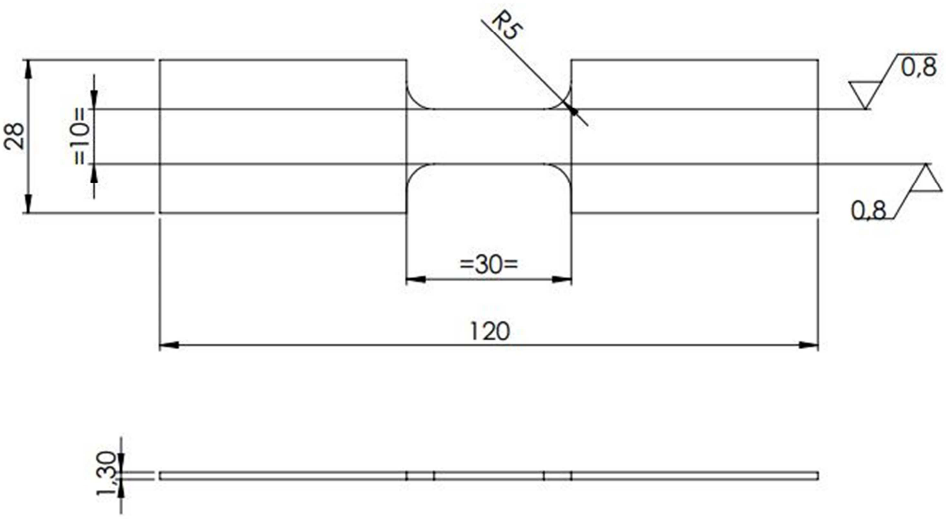


Fig. 1 The shape of the sample

With the aim of simulating the heat strain just like in the case of spot welding, the samples were subject to the heat loading induced by:

- resistive heating accelerated by air cooling:
  (CM-01, CM-02, CM-03 – martensitic steel)
  (CD-01, CD-02, CD-03 – dual phase steel)
- resistive heating not accelerated by air cooling:
  (NM-01, NM-02, NM-03 – martensitic steel)
  (ND-01, ND-02, ND-03 – dual phase steel)
- Originals spots wels:
  (BM-01, BM-02, BM-03 – martensitic steel)
  (BD-01, BD-02, BD-03 – dual phase steel)

The main emphasis was put on reaching limit sample temperatures below 707°C, which is the critical temperature of the examined materials.

Cooling rate curves are shown in the Fig. 2

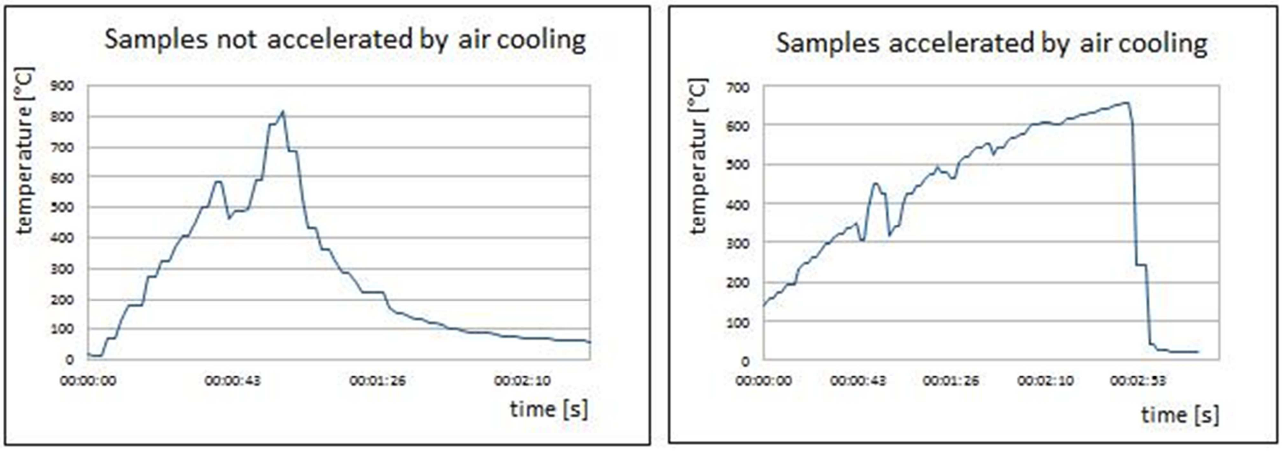


Fig. 2 *Cooling rate*

4 The range and the intensity of the heat influence

In relation with the above mentioned influence on fracture behaviour, the evaluation of the zone position with minimum strength and the intensity of the strength loss were performed as a default analysis of the welded joints. Measurement of the microhardness was performed in lines which lead through the centre of the heat influenced areas of the individual samples. Verification of the proper level of tempering was based on the hardness measurement. Comparison of experimental vs. real (i.e. due to welding technology) softening process is displayed in the Fig. 4

This measurement was precise enough to detect local differences of the individual heat affected zone sublayers (Fig. 3).

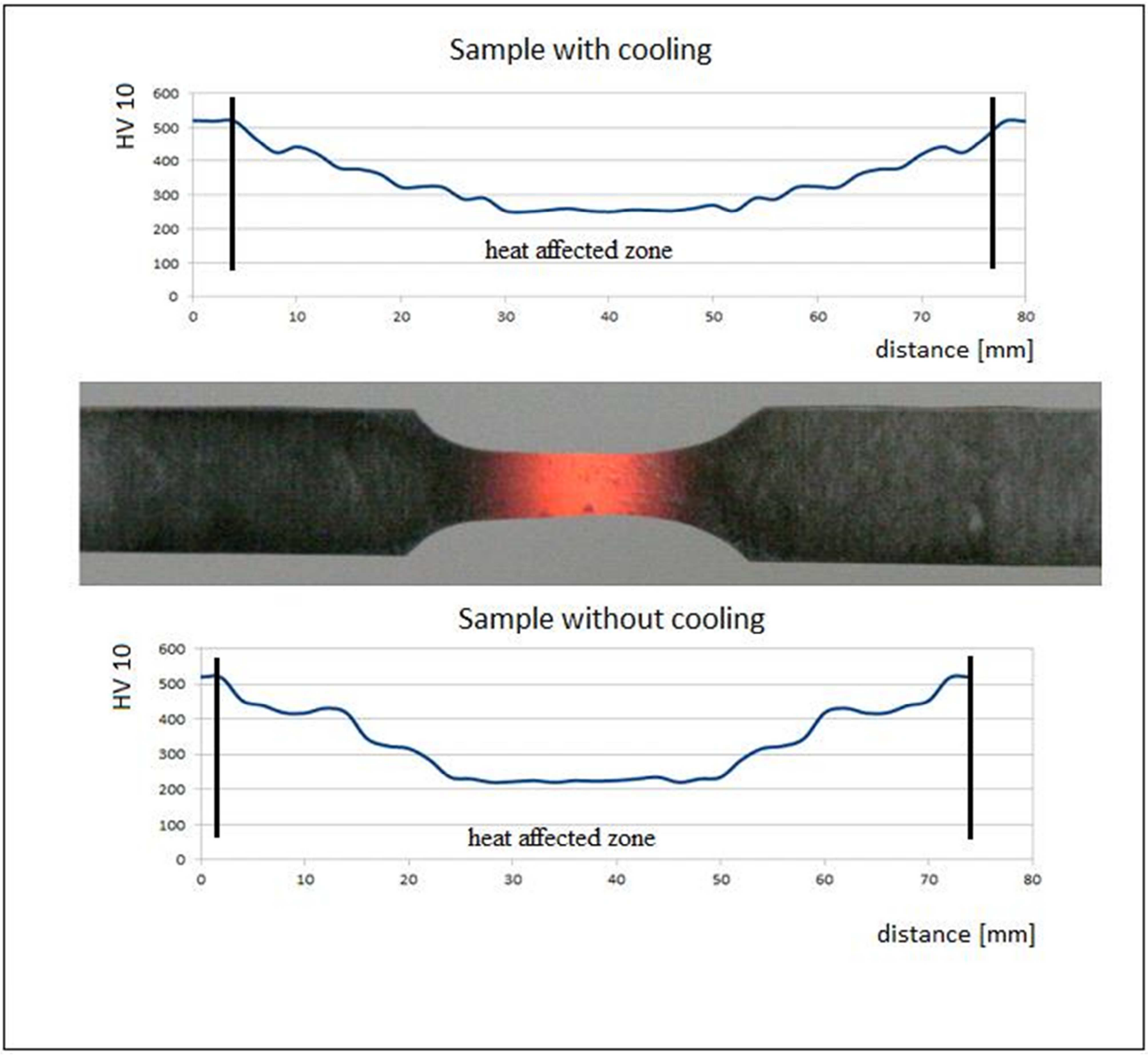
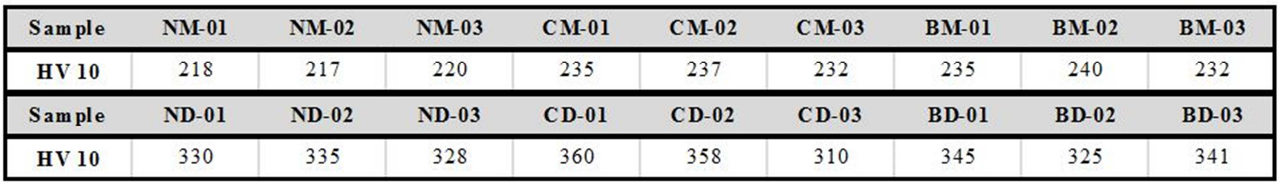


Fig. 3 *Changes microhardness in heat affected zones*

The resultant hardness loss of the samples, presenting the influence of the spot weld, is displayed in the Fig. 3. During the measurement, almost stable values of the highest strength loss were observed in the affected area in comparison with the simulated heat influence, see in the Fig. 4.



Sample	**NM-01**	**NM-02**	**NM-03**	**CM-01**	**CM-02**	**CM-03**	**BM-01**	**BM-02**	**BM-03**
HV 10	218	217	220	235	237	232	235	240	232
Sample	**ND-01**	**ND-02**	**ND-03**	**CD-01**	**CD-02**	**CD-03**	**BD-01**	**BD-02**	**BD-03**
HV 10	330	335	328	360	358	310	345	325	341

Fig. 4 *Values of strength in head affected zone*

5 The application of the indentation method of the strength differences evaluation

As yet another source of information which can describe the changes of the mechanical properties in the critical areas, the indentation method can be used. The standard way of measuring is the Martens hardness, however, it does not enable the straightforward evaluation of the elastic-plastic material response because there is a significant influence of the contact surface change of the indentor during loading. In order to authenticate the measurement possibilities of the local changes of the mechanical properties with this method, a cylindrical indentor with a diameter of 1,2 mm was used [8].

The cylindrical indentor was applied into the areas of the simulated heat influence.

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 behavior 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 [9].

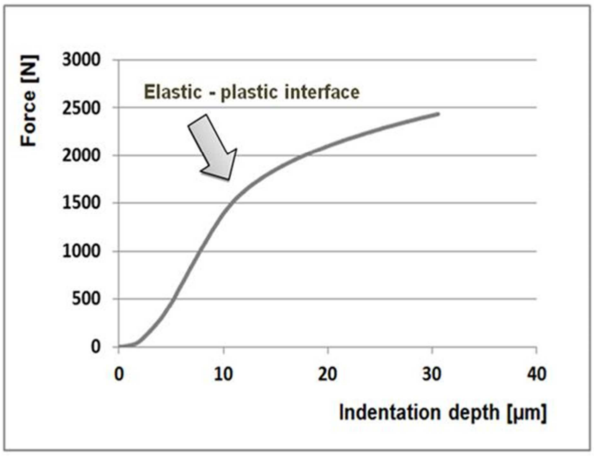


Fig. 5 *Process of indentation method*

The values of the yield strength obtained by the indentation test and compared to the values obtained by the pull test show the maximum dispersion about 3% (Fig. 6).

Sample	Indentation Method [MPa]	Yield Strength – tensile test [MPa]	Sample	Indentation Method [MPa]	Yield Strength – tensile test [MPa]
NM-01	620	633	**CM-01**	670	680
NM-02	625	640	**CM-02**	660	672
NM-03	620	635	**CM-03**	666	678
AVERAGE	**622**	**636**		**665**	**677**
Sample	**Indentation Method [MPa]**	**Yield Strength – tensile test [MPa]**	**Sample**	**Indentation Method [MPa]**	**Yield Strength – tensile test [MPa]**
ND-01	720	733	**CD-01**	750	765
ND-02	725	738	**CD-02**	755	770
ND-03	695	705	**CD-03**	750	768
AVERAGE	**713**	**725**		**752**	**768**

Fig. 6 *Indentatiom method vs. Method Yield Strength*

6 Evaluation based on microstructure and fracture behaviour

Impact of the experimental temper treatment can be seen from different microstructure, see in the Fig. 7. compared to Fig. 8. The initial microstructure of the steel type 22MnB5 consists mainly from martensite with minor phase of ferrite and bainite (Fig. 7). Substantial content of ferrite was observed typically in connection with local decarburization in case of damage of the surface Al-Si coating. Tempered martensite was observed as a result of temper treatment (Fig. 8), i.e. in full concert with the softened sub-layer of the heat affected zone.

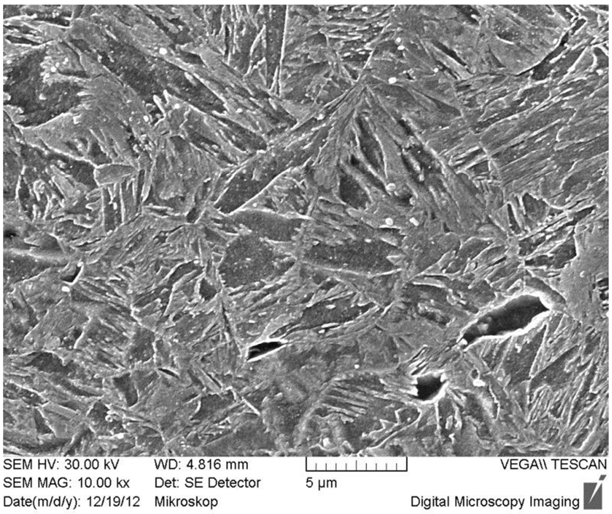


Fig. 7 *Unaffected microstructure of 22MnB5 steel*

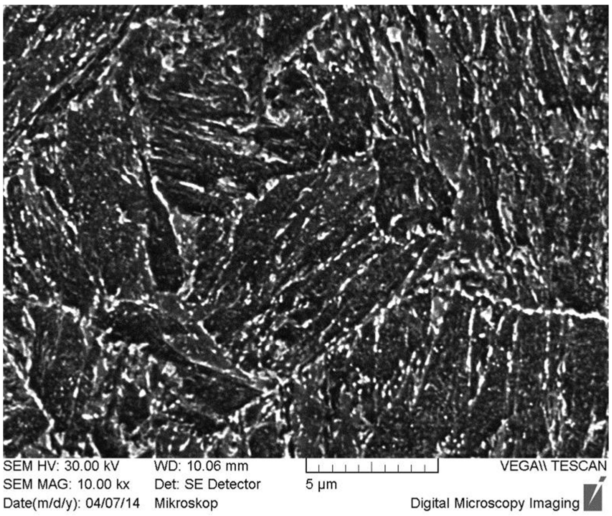


Fig. 8 *Simulated heat affected microstructure*

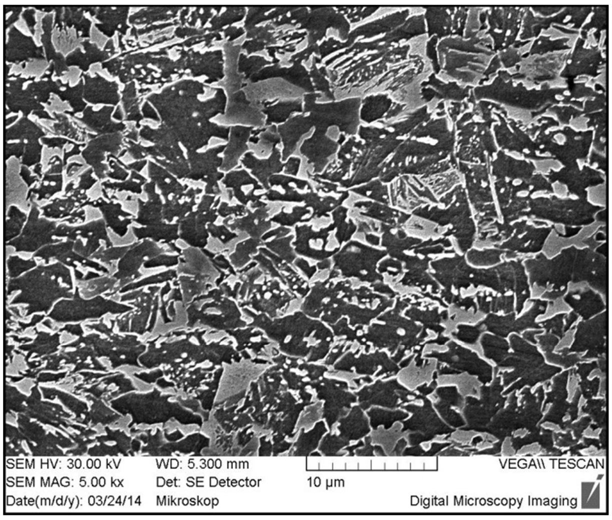


Fig. 9 *Unaffected microstructure of dual phase steel*

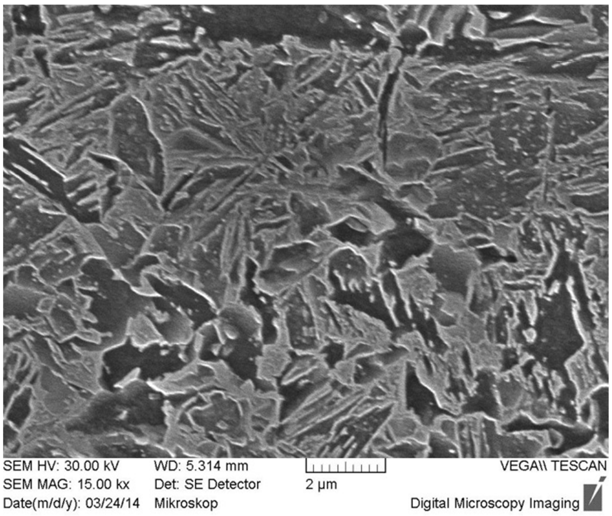


Fig. 10 *Simulated heat affected microstructure*

The same heat influence led in DP steel to the grain coarsening in the zone adjacent to the fusion line – see Fig. 10. As a second softening process we can consider an decrease of previous dislocation strengthening. Micro-volumes of tempered martensite with very small carbides was observed in substantial part of the heat affected zone.

An important question is the impact of temper gradient on fracture behavior. Ductile fracture mode is typical for real damage of welds in softened zone, even at high strain condition. Improper temper conditions may lead to undesired carbide precipitation.

7 Conclusion

The spot welding of the high strength steels brings problems related to the decrease of strength in the critical heat affected zone. The intensity of the strength loss and the joint geometry influence the strength of the joints as well as the energy consumption of the dynamic endurance of welds.

This work presents the input experiments with the aim of setting a methodology which would lead to an assessment of the mechanical property changes which appear during the heat loading. The performed experiment is oriented to the evaluation of the yield strength with the help of the indentation methods. As a verification of the methodology, there is the comparison of the indentation method and the tensile data

The tool for the indentation method was the cylindric indentor with the diameter of 1,2 mm, which later lead to the need to simulate the heat affected areas. An evaluation of experimental temper loading was based on the structural and fractography analyses. The microstructure of a tempered martensite of steel 22MnB5 was observed after experimental treatment in full accordance with the welding process influence. In terms of the fracture behavior the primary ductile fracture mode was confirmed too. An influence of precipitated carbides was observed as a source of local decrease of plasticity.

Presented results suggest used methodology as a possible way to solve a problem; for validation of methodology the higher number of tested samples is needed.

In order to test the local areas of the examined materials, which are in intervals around 200μm, it is necessary to create an indentation tool whose diameter is smaller than the heat affected zone.

The results confirm good prospects of the method which would enable the assessment of the strength differences in the narrow heat affected zone. For the needs of the numeric prediction of the static strength of welds, it is also necessary to verify abilities of the above stated method for the evaluation of the plastic area of the loading, i. e. the differences in the mode of deformation hardening.

8 References

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