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INFLUENCE OF THE WELDING PROCESS ON THE MARTENSITIC HIGH STRENGTH STEEL

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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].

Martensitic 22MnB5 steel is widely used steel grade in automotive application. Initially, the material exhibits a ferritic–pearlitic microstructure. After the hot stamping process, the components finally have a martensitic microstructure with a total strength of about 1500MPa. In order to achieve martensitic microstructure, the blank has to be austenitized in a furnace for at least 5min at 950 ◦C. The blank is formed and quenched simultaneously at a cooling rate of approximately 27 K/s. At a temperature of around 400 °C, a diffusionless martensitic transformation will be induced, which finally is responsible for the resulting high strength of the part [2].

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 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. 2.1) were prepared from the 22MnB5 steel with 15-20μm thick Al-Si anticorrosive surfaces, which ensure corrosion protection during hardening by moulding.

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, 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 [3].

Tab. 2.1. *The basic composition of martensitic steel material [wt%]*

Sample	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Ti	B
22MnB5	0.25	1.25	0.25	0.02	0.002	0.19	0.01	0.02	0.043	0.04	0.004

The development of weld-joint fractures

The local decrease of strength in heat affected zone resistive welds substantially influences the nature of the destruction of the welds during static and dynamic loading. As it results from the previous experiments, there are three basic developments of fractures [4].

- The fracture between the weld metal and the heat affected area (“A” in Fig. 2.1). This type of fracture is permissible from the viewpoint of the standard operational requirements but it is not considered to be the optimal option from the viewpoint of the achievable strength.
- The fracture in the weld metal (“B” in Fig. 2.1). It appears especially as a result of material anomalies of welded sheet metal and both internal defects and the defects of the Al-Si surface layer. The joint made in this way achieves the lowest level of possible strength.

- The fracture in the heat affected area sublayer ("C" in Fig. 2.1) with the minimal strength shows optimal results of the achievable joint strength and the consumed energy during0 destruction. In this type of fracture, a part of the destructive energy is transferred into the heat unaffected parts of material and thus even increases the absolute value of the consumed work.

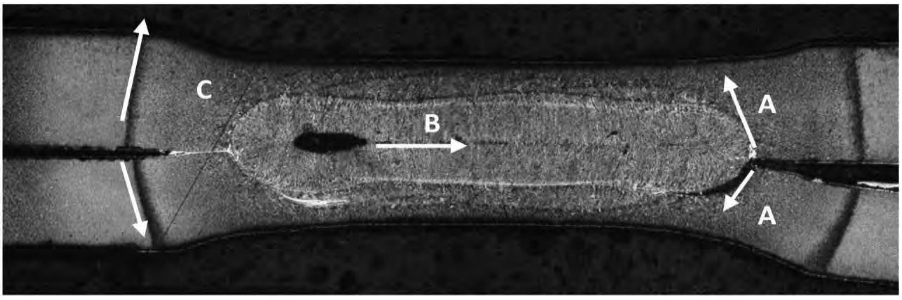

Fig. 2.1. *The typical fractures of the weld joints*

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. 2.2). The samples were cut from flat carbody parts intended for spot welds.

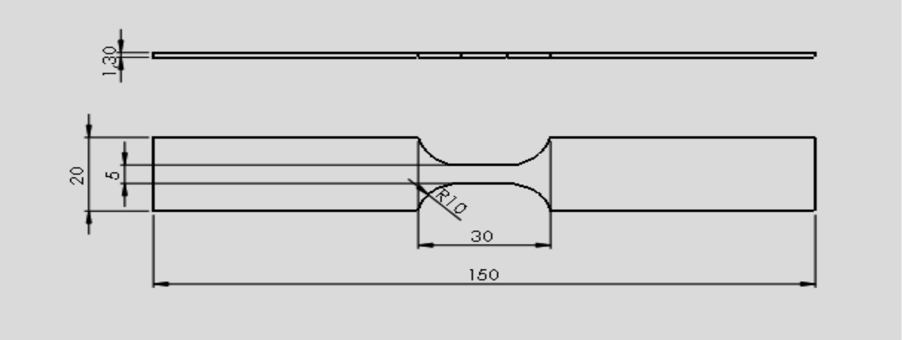

Fig. 2.2. *The shape of the sample*

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: C-01-01, C-01-02, C-01-03
- resistive heating not accelerated by air cooling: N-01-01, N-01-02, N-01-03
- spot welded: B-01-01, B-01-02, B-01-03

The main emphasis was put on reaching limit sample temperatures below 707°C, which is the critical temperature of the examined materials. This temperature was obtained from this relationship [5]:

$$A_{c1} = 721 - 14\%Mn + 22\%Si - 14{,}4\%Ni + 23{,}3\%Cr\ [°C] \tag{1}$$

Cooling rate curves are shown in the Fig. 2.3

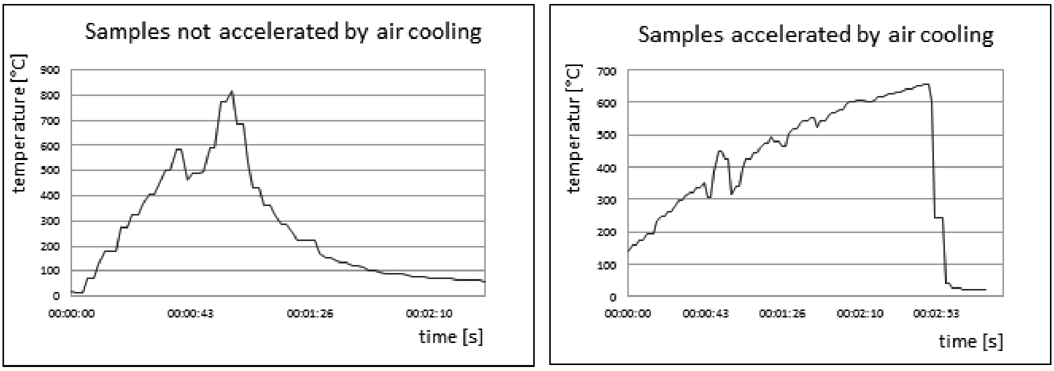

Fig. 2.3. *Cooling rate*

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 Tab. 2.3.

This measurement was precise enough to detect local differences of the individual heat affected zone sublayers (Fig. 2.4).

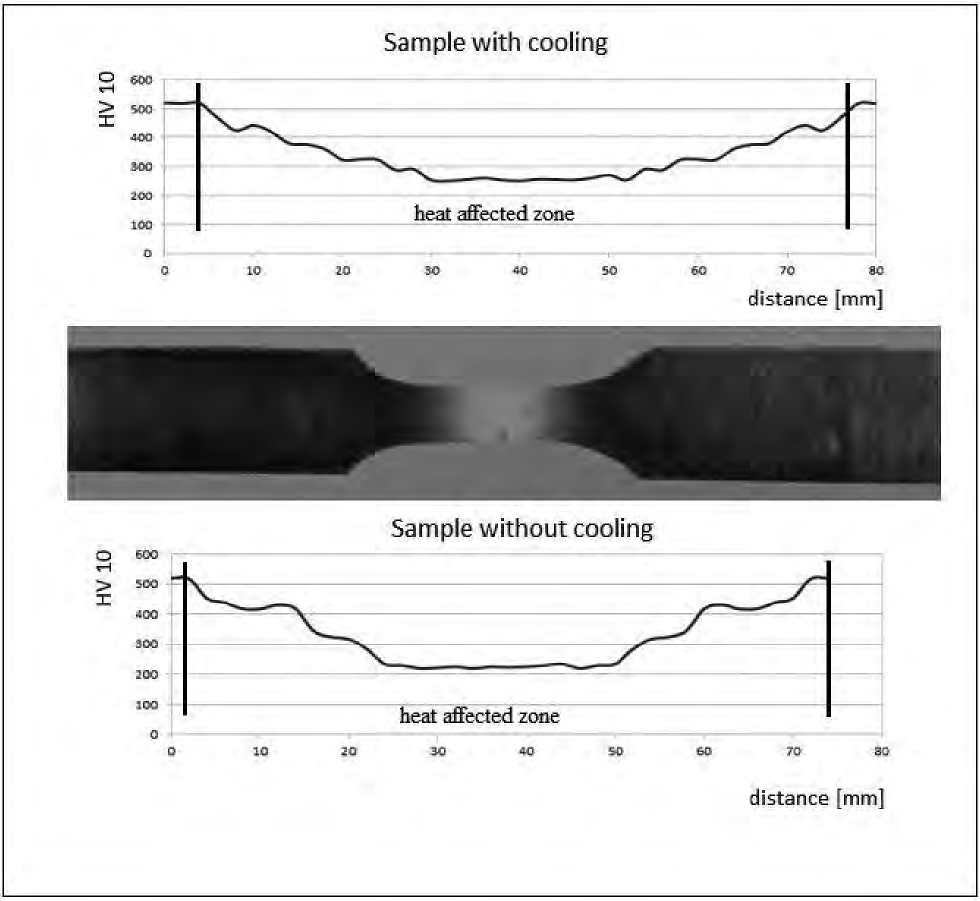

Fig. 2.4. *Changes microhardness in heat affected zones*

The resultant hardness loss of the samples, presenting the influence of the spot weld, is displayed in the Fig. 2.2. 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 Tab. 2.2.

Tab. 2.2. *Values of the highest strength loss*

Sample	N-01-01	N-01-02	N-01-03	C-01-01	C-01-02	C-01-03	B-01-01	B-01-02	B-01-02
HV 10	218	217	220	235	237	232	235	240	232

The evaluation of the heating influence on the tendency of the deformation hardening

In order to get deformation characteristics of tension-deformation, tensile tests of the samples after the simulated heat loading were performed; the samples number of N and C with the 1.3 mm thickness were examined.

In order to compare the intensity of the heat influence, the comparative tensile tests of high-strength material qualities in their original state, i. e. without the heat influence (number of B), was performed.

The results of the tensile test were transformed in compliance with ČSN ISO 10275 into the true stress-strain values [6]. A validity range of these relations was chosen for each sample together with the corresponding value of the deformational hardening exponent (Tab. 2.3).

Tab. 2.3. *The value of the deformational hardening/strength*

Sample	Fmax [N]	$Rp_{0,2}$ [MPa]	Rm [MPa]	n
C-01-01	5733	780	1040	0,74
C-01-02	5055	680	853	0,71
C-01-03	5050	675	860	0,71
N-01-01	4184	615	743	0,51
N-01-02	4166	724	731	0,54
N-01-03	3590	753	615	0,54
B-01-01	9573	945	961	0,82
B-01-02	11546	950	982	1,35
B-01-02	11268	900	939	0,86

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 1,5 mm was used.

The methodology is based on the assessment of the loading part of the indentation curve. From the 2nd derivation, we can obtain the inflection point, (Fig. 2.5), whose coordinates correspond with the force necessary to reach the yield strength [7].

From the series of the measured indentation curves, there was a difference in the beginning of the loading curve record. The difference is repeated in each indentation with a different shape and inclination. We consider the influence of:

- the surface deformation of the sample during the tool application
- the deformation of the intendor
- high requirements on surface quality for the method application.

The cylindrical indentor was applied into the areas of the simulated heat influence. When the size of the tool is considered, it was only possible to use the samples which were subjected to the heat loading in the furnace or resistive-heating.

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% (Tab. 2.4).

Tab. 2.4. *Indentation Method vs. Method Yield Strength*

Sample	**Inflection Point [N]**	**Indentation Method [MPa]**	**Yield Strength – tensile test [MPa]**
C-01-01	1100	760	780
C-01-02	1050	700	680
C-01-03	1080	720	675
N-01-01	1120	631	615
N-01-02	1140	715	724
N-01-03	1150	730	753

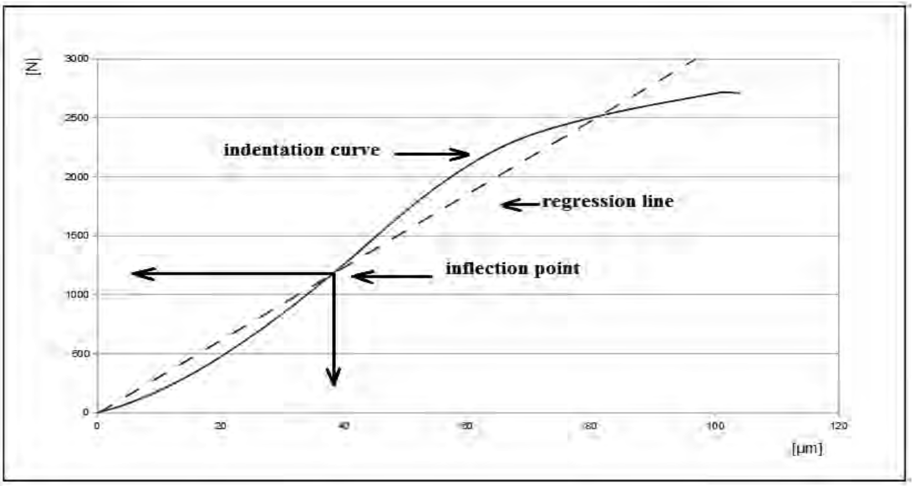

Fig. 2.5. *Process of indentation method*

Evaluation based on microstructure and fracture behaviour

Impact of the experimental temper treatment can be seen from different microstructure, see in the Fig. 2.6. compared to Fig. 2.7. The initial microstructure of the steel type 22MnB5 consists mainly from martensite with minor phase of ferrite and bainite (Fig. 2.6). 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. 2.7), i.e. in full concert with the softened sub-layer of the heat affected zone.

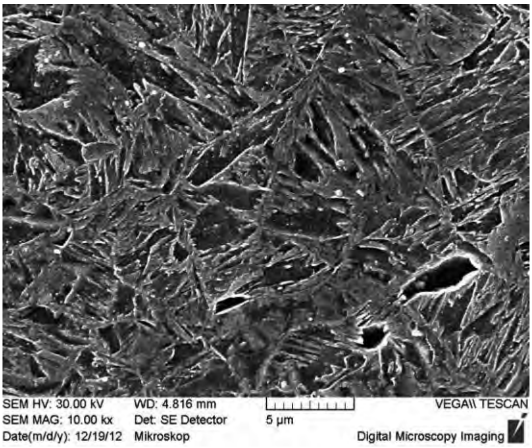

Fig. 2.6 *Unaffected microstructure of 22MnB5 steel*

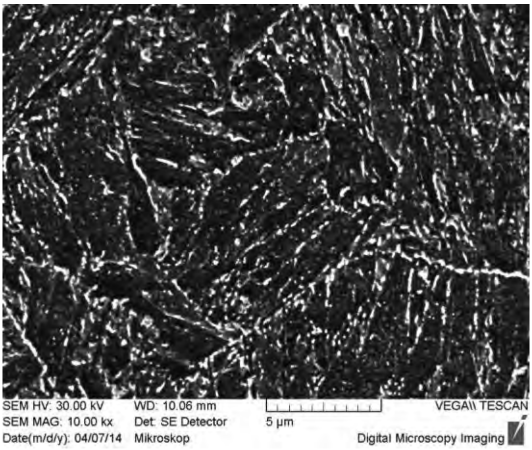

Fig. 2.7 *Simulated heat affected microstructure*

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.

Preference of the rough carbides along the grain boundaries can suppress the prior positive tendency to high energy fracture. Fig. 2.8. presents the ductile fracture of the simulated heat affected zone. Partially lowered plasticity was observed in micro-volumes near to typical impurities, or local higher content of carbides. Fracture morphology with more shallow shear necking including of mentioned influence of carbides is presented in Fig. 2.9.

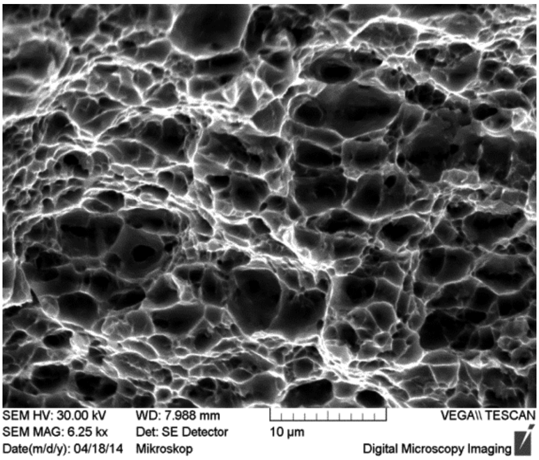

Fig. 2.8 *Fracture mode of steel after experimental heat treatment*

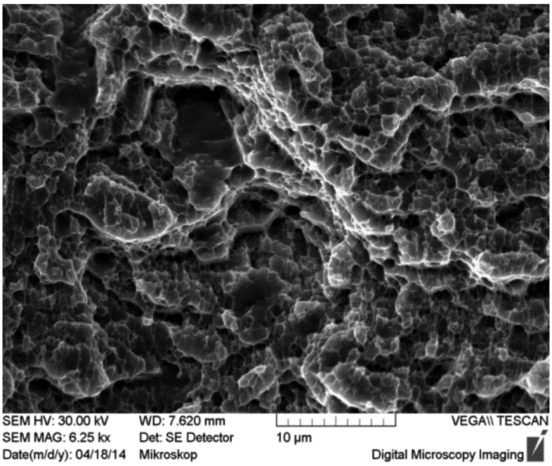

Fig. 2.9 *Local influence of coarsened carbides and impurities*

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, which were converted into the real ones.

The tool for the indentation method was the cylindric indentor with the diameter of 1,5 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 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.

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Resumé

VLIV SVAŘOVACÍHO PROCESU NA MARTENZITICKOU VYSOKOPEVNOSTNÍ OCEL

Petr HANUS, Eva SCHMIDOVÁ, Josef TOMANOVIČ

Předmětem této studie jsou Martenzitické oceli 22Mn5B využívané v automobilovém průmyslu. Hlavním cílem provedených analýz je studium mechanických rozdílů v tepelně ovlivněné oblasti, v důsledku bodového svařování. Vznik tepelně ovlivněné oblasti je experimentálně simulován různými způsoby. Cílem této práce je zjistit optimální metodiku pro stanovení meze kluzu a popsat zpevňující tendence v těchto zónách.

Summary

INFLUENCE OF THE WELDING PROCESS ON THE MARTENSITIC HIGH STRENGTH STEEL

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The subject of the study are martensitic 22Mn5B steels, 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. The aim of the work is to determine the most suitable methodology for evaluating the local changes of the elastic-plastic material response. The aim of this work is to determine the optimal methods for the determination of the yield strength and to find a firming trend in these zones.