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Modeling of laser-welded blank formability

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Abstract – A laser-welded blank (LWB) offers several notable benefits including decreased part weight, reduced manufacturing costs, increased environmental friendliness and improved dimensional consistency. However, in order to take advantage of these benefits, designers need to overcome the formability of LWBs and be able to accurately predict the LWB forming characteristics early in the design process. We present a new approach to predict the maximum elongation of the laser seam; for example, for Advanced High-Strength Steel (AHSS)-based LWBs. This approach is based on a coupling model taking into account the thermal, metallurgical and mechanical phenomena. A comparison of numerical and experimental results shows very good agreement. These approaches offer a considerable advantage in obtaining the formability limits for all configurations.

Automotive designers are constantly searching for innovative means of reducing vehicle weight and manufacturing costs. This goal can be reached through the use of AHSS-based Laser-Welded Blanks (LWBs). This technology consists of steels of different thicknesses and grades welded together to produce a single blank prior to the forming process. However, designers need to overcome the formability of LWBs and be able to accurately predict unique characteristics related to LWB forming early in the design process.

In a general manner, the formability of laser-welded blanks can be limited by ruptures taking place either in the base metal far from the welded seam, in the vicinity of the laser seam or in the laser seam.

Many procedures have been developed in the past to evaluate sheet metal formability [1–3]. For Laser-Welded Blank applications, many recent formability studies have been performed to predict the risk of failure in the base material close to the weld. A method based on a specific forming limit curve for LWBs is proposed by Cayssials [4]. Making good use of technological progress, a new numerical solution to detect the onset of necking by the strain rate method was proposed [5].

However, those studies focused only on the risk of failure occurring in the base metal. A fracture occurring transversely to the weld has rarely been studied. A fracture occurring transversely to the laser seam is highly dependent on the laser welding parameters and weld properties. On the other hand, different studies focusing on heat source modeling to simulate the full penetration laser welding process (in relationship to weld parameters) can be found in the literature [6]. Finally, different techniques have been developed to identify and optimize the weld parameters to improve the applicability of numerical simulations of welding processes [7,8].

This paper presents an innovative approach developed in order to predict accurately a fracture transverse to the laser seam. This model is based on theoretical and numerical analysis of the phenomena involved.

1 Fracture modes of Laser-Welded Blanks

In the stamping process of automotive components, a crack will occur when the deformation of the blank exceeds a critical value. In a general manner, the formability of laser-welded blanks can be especially limited by a fracture occurring in the vicinity of the laser-welded seam.

For particular grade combinations and forming conditions, the fracture initiation can occur in the laser-welded seam with a crack perpendicular to the weld line. In this case, the formability depends on the weld

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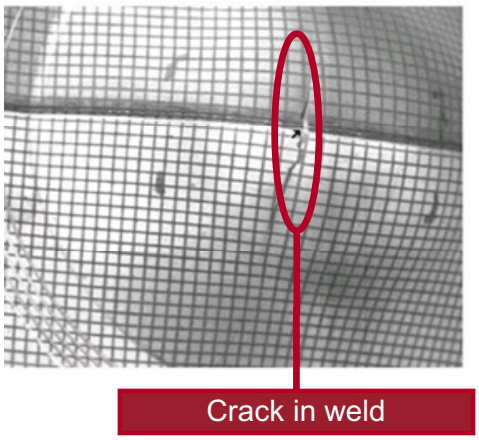


Fig. 1. Fracture in weld seam.



Fig. 2. Fracture on the part.

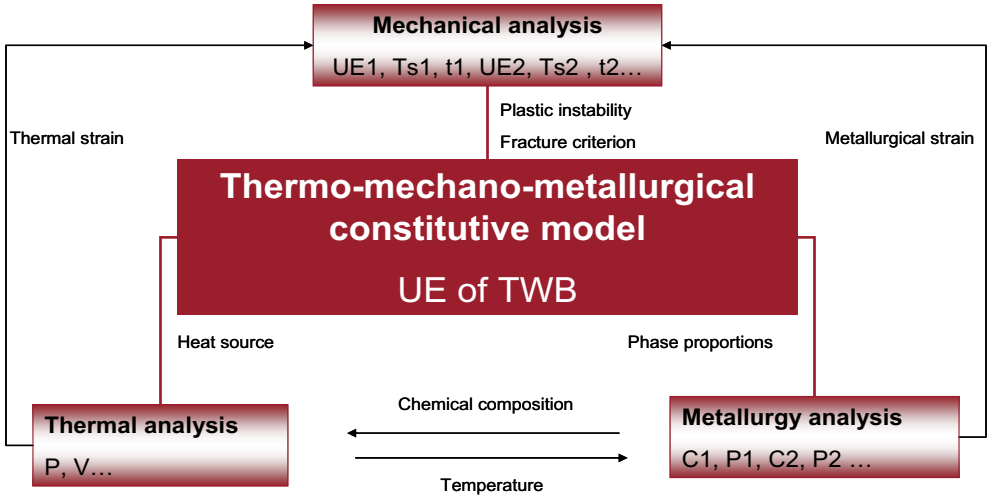


Fig. 3. LWB behavior: interrelated physical phenomena.

properties. Currently, no existing model able to determine the formability limit of the laser seam itself is available. One reason is the high complexity of this issue, related to the metallurgy of the molten zone, which is strongly influenced by the steel chemical composition and the welding conditions.

2 Prediction of maximum elongation of laser seam

2.1 Fracture characterization

The weld seam maximum elongation needs to be taken into consideration (when considering a given geometry, grade selection and thickness allocation) to avoid a fracture in the weld during a forming operation. In this case, the formability in the direction of the weld line depends on the weld and base material properties.

In order to avoid a fracture in the weld during the stamping process of the laser blank, it is necessary that the strain levels remain below the critical elongation everywhere in the laser seam.

The experimental analysis shows that weld seam fracture analysis needs to take into account many parameters including the temperature/time history during welding, the steel chemical composition and the mechanical properties for each constitutive base metal.

To determine the plastic instability conditions (strain localization) in the weld, we need to forecast the mechanical properties

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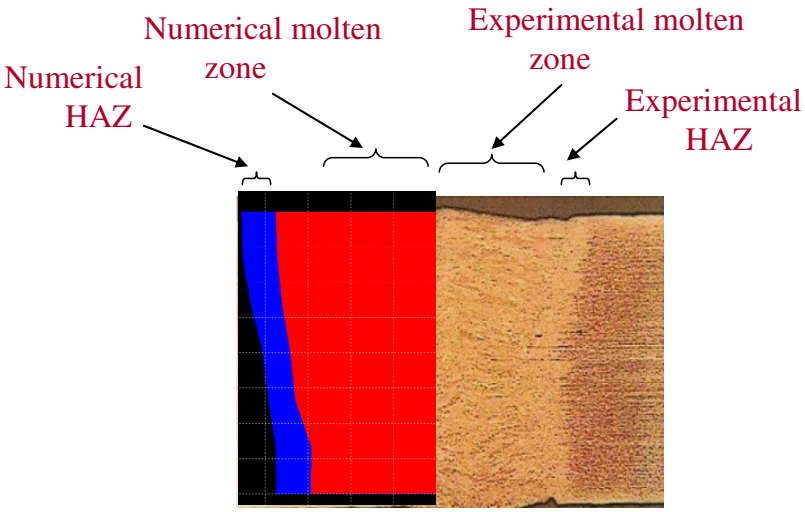


Fig. 4. 2D cross-section of the weld; comparison of numerical and experimental weld pool geometry.

of the molten zone and the heat-affected zone (Fig. 3). The prediction of the mechanical properties of the weld will be deduced from the mechanical properties and the ratio of each metallurgical constituent. Finally, the metallurgical constituent hardening is related to the chemical composition and the welding process conditions (including the cooling rate).

2.2 Modeling of laser welding process

Modeling of the laser welding process is particularly complex as it needs to describe the heat transfer, and it is necessary to know the metallurgical transformations and the temperature dependency of the thermal and mechanical properties of the materials. Some studies have shown that SYSWELD software allows a coupled resolution which takes into account the heat conduction equation and the kinetics of metallurgical transformations.

A design of the experimental and numerical response surface approach was used to estimate the weld pool geometry. Figure 4 shows a comparison of the numerical and experimental weld pool geometry of both the molten zone and Heat-Affected Zone (HAZ). This numerical model is used to estimate the thermocycle even in the weld, and in the HAZ, in order to forecast the metallurgical transformations.

Another key point of a coupled modeling is the accuracy of the phase transformation prediction. It is known that phase transformations in steel influence the weld seam ductility. A finite element model was used to estimate phase transformations in conjunction with thermal analysis, taking into account the thermal gradient and the Continuous Cooling Transformation diagram (CCT).

Figures 5a and b show two examples of phase transformations during the laser welding process. It can be pointed out that in the case of AHSS grades the final laser seam microstructure is fully martensitic.

The prediction of the mechanical properties of the weld is made from the mechanical properties of each constituent by applying a simple mixture rule.

In the specific case of a fully martensitic structure, the constitutive law is strongly dependent on the average carbon content, as the carbon content is known to be a key factor in the martensite hardness. Figure 6 gives an example of a stress-strain curve determined from the modeling of the martensite mechanical behavior.

If we assume that the weld fracture occurs in a ductile manner, the analysis of the plastic instability and strain hardening is applied to develop a prediction of the mechanical properties for the laser weld seam. The hypothesis of ductile fracture was validated experimentally, as illustrated in Figure 7.

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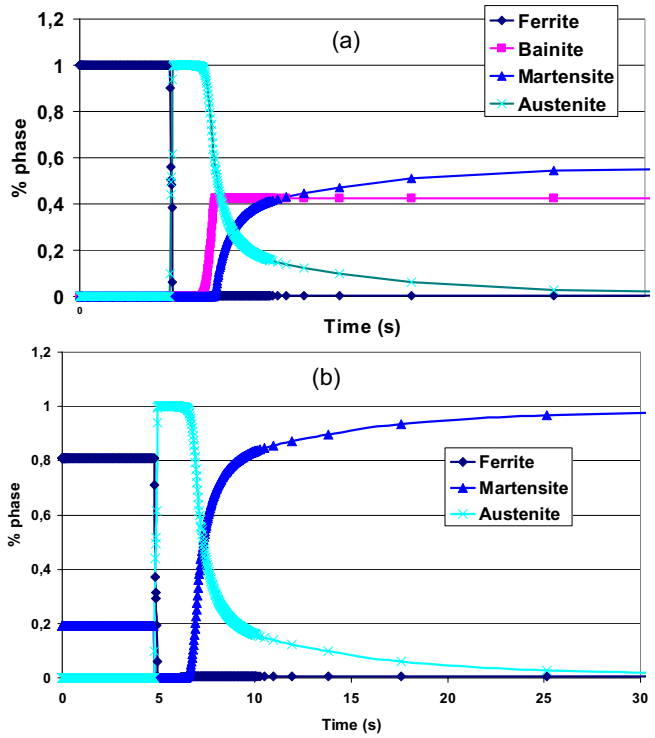


Fig. 5. Prediction of metallurgical transformations during welding: (a) Mild Steel (b) AHSS.

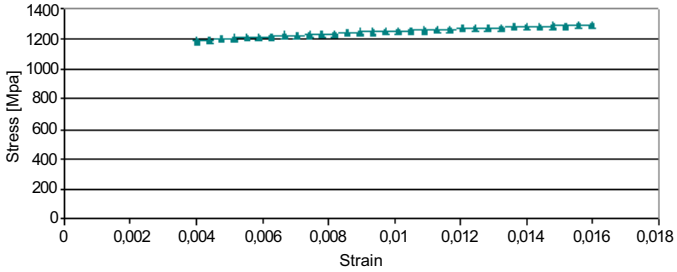


Fig. 6. Example of laser weld seam plastic behavior for a small strain level in the case of AHSS.

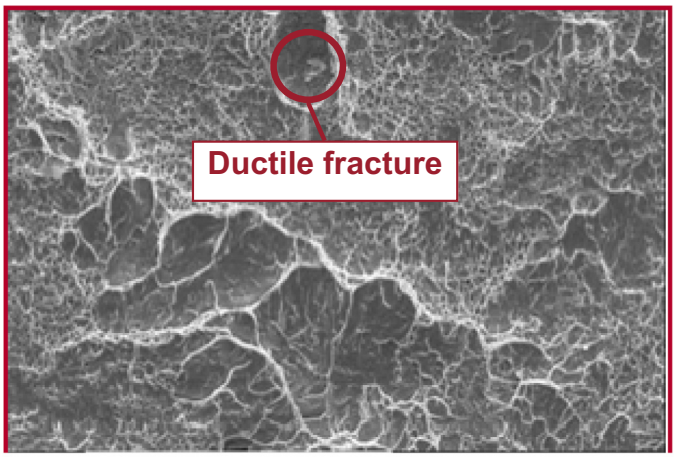


Fig. 7. Example of fracture morphology in a welded seam.

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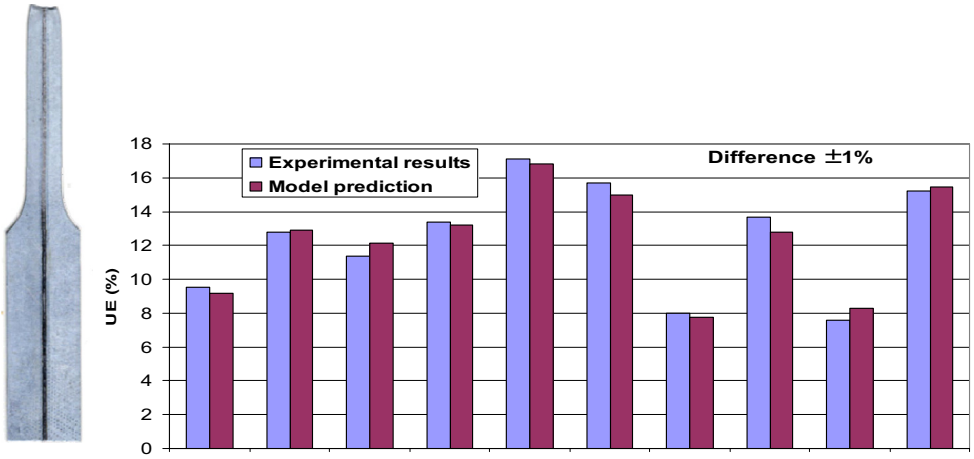


Fig. 8. Comparison of measured Ultimate Elongation with predictions based on a new model for a full range of AHSS-based LWB assemblies.

2.3 Experimental validation

In order to check the accuracy of the modeling, a series of mechanical tests were performed on several AHSS combinations. The specimen geometry is shown in Figure 8.

Various configurations of assembly were tested, with a large variety of thickness gauges, and with various steel grades such as DualPhase 600, DualPhase 780, DualPhase 980, TRIP 700, TRIP 800 and Multiphase 1000, all obtained using the ArcelorMittal dedicated welding process. The results obtained are gathered in Figure 8. They clearly show the very good accuracy of the modeling.

We can also point out the good maximum elongation obtained in most cases, which opens up a large range of applications for the steel combinations considered when these materials are properly welded using a dedicated process.

3 Conclusions

AHSS-based LWBs offer several notable benefits including decreased part weight and reduced manufacturing costs. However, it is important to accurately predict the formability during the deep drawing process.

To ensure the feasibility of stamped parts made of LWBs, a model was developed to predict the fracture transverse to the butt laser-welded assembly. The experimental results show excellent agreement between the experiments and both model predictions.

With the full range of AHSS grades and the dedicated welding process developed within ArcelorMittal, this model allows one to properly design high-performance AHSS-based LWB solutions, especially dedicated to crashworthiness improvement and lightening of the body in white.

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