Detecting Acoustic Events during Thermal and Mechanical Loading

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Abstract. We examined Acoustic Emission (AE) events during combined heat and tensile test carried out in different steels (S235JRG2, TRIP and TWIP steels) on Gleeble simulator. The simulator enabled us to control parameters for fast heating and cooling parallel with pressing and tensile the sample until its real break. The aim was to investigate the structural change of the material, phase transformation in the steel at different temperatures, and connect them to signatures measured by acoustic emission sensors.

During testing we noticed characteristics of Barkhausen noise. We demonstrate and prove definitely that we were facing Acoustic Barkhausen Noise (ABN) due to AC current used to heating and to maintaining the temperature in the cylindrical ferritic sample. It was observed, that the magnitude of the ABN dropped suddenly to the half when the tensile test started after preheating, and it was growing back when the tensile test went to plastic deformation with elongation of the tested sample. Localization of the ABN sources has been done showing the distribution of the sources along the whole material. ABN sources were observed all along the sample with interesting density growth in the section where the diameter was smaller, thus the tension was higher. Nevertheless, this was not the only observation, since the place of the densest sources was displaced from one position to another position until the break occurred near to the densest place of ANB and AE source.

Off-line examination of the structure of material afterward using destructive test proved that we could register those cooling periods, where phase transition took place in the material. Ferrite-bainite and magnetite-bainite transitions were connected to some higher distribution of ANB and AE signals during the test. Rate of hits and sum of hit were connected to material transition during cooling.

The first results of AE measurements during tensile test in TWIP materials showed that AE events are connected with the well known sequences of hardening rate.

Introduction

The idea to use acoustic emission (AE) measurement during tensile test is almost as old as the history of the AE investigation. In 1949 the godfather of AE J. Kaiser began his work in his famous PhD publication with detecting of AE hits during tensile test [1]. Afterward the interest of application of AE toward material investigation was dropping, mainly because the sensitivity of the AE detection and the analog data evaluation technique made almost impossible to distinguish different AE event for different sources of emission. But in the last two decades the revolution both in digital techniques and in the electronics opened the way to detect and to evaluate acoustic events with high sensitivity and with such parameters as spectral estimation and high frequency sampling, which newly opened the way to use AE for discovering acoustic emissions due to structural changes, phase transformation and other occurrences in the metal (see for example [2,3,4]. The appearance of new types of steel for automotive industry (for example TWIP steels [5,6] and the long term operation of nuclear power plants request new techniques to be involved in material testing to ensure tracking structural changes both in thermal and mechanical treatments. In nuclear industry for example there is a growing demand for monitoring degradation by non-destructive methods, since after destruction no way to operate the component anymore.

We report here some measurement of acoustic events registered by AE sensors in various contemporary steels.

Measuring devices

The main device for thermal and mechanical loading was a Gleeble 3800 type physical simulator. This allowed us to change or keep the temperature on a programmed way with heating-cooling rate in principle up to 10000^{o}C/s. We did not use that capacity in the given experiments ensuring to maintain bainite / martenzit phase transition and other kind of structure changes in the material in a planned and programmable way. Meanwhile the simulator can also press or tension the specimen with force up to 50kN also in preprogrammed way. We made use of that possibility mainly at the end of thermal loading; we made also conventional tensile tests at different constant temperatures. Meanwhile we made our AE measurements to learn what kind of acoustic hits can be registered during such treatments.

Our acoustic emission sensors were A-150 type, Ukraine products with resonance frequency of about 150 kHz, with not too sharp resonance. It had been built in preamplifier and a magnetic foot, which was not really used since we frequently had austenitic material and even TWIP (twinning induced plasticity) steel, which had absolutely no ferrite content. We mainly used the old-fashioned beeswax as adhesive and sound transmission material, which seemed to us ideal for such investigation.

For AE data collection and data evaluation in this paper we mainly used the AED-40 commercially available AE system. This system has extra log and lin amplifiers with adjustable threshold limits, calibration for sound velocities in that material and all traditional parameter estimation: time of hits, amplitude of hits, duration, counts, rise time, plus it has a built in event recognition software which work very well especially for such a simple one dimensional case. We had only two sensors in the presented experiment. We did not have guards as in our previous experiments [7], since our experience showed that it was not necessary in this simulator, and we were lack of the place as well. We are also developing our own AE measuring system presented in this conference [7,8] mainly to understand the nature of the Barkhausen like events as explained in more details in [8].

We also made a detailed post processing using mostly Origin. Making use of the delay time between the two sensors on the two ends of the specimen we estimated the place, i.e. the source point of the AE events registered parallel by the two sensors. If the delay time is less than defined by the half of the length of the specimen and the sound velocity in the material, then it is easy to calculate the place where the sound was born (localization of the event) at least in axial direction. This was translated then to localization points (red dots on all pictures in the next). We also calculated the true elongation and the true stress in the tensile test, where it was inevitable for explanation.

2. Measurements and results on TRIP steel

Experiments were carried out in mentioned simulator using a plate sample made form TRIP (transformation induced plasticity) steel with parallel registration of the acoustic events. Fig. 1 shows the plate specimen between the jaws of the simulator with two AE sensors and the thermocouple in the middle of the plate for controlling the temperature behavior.

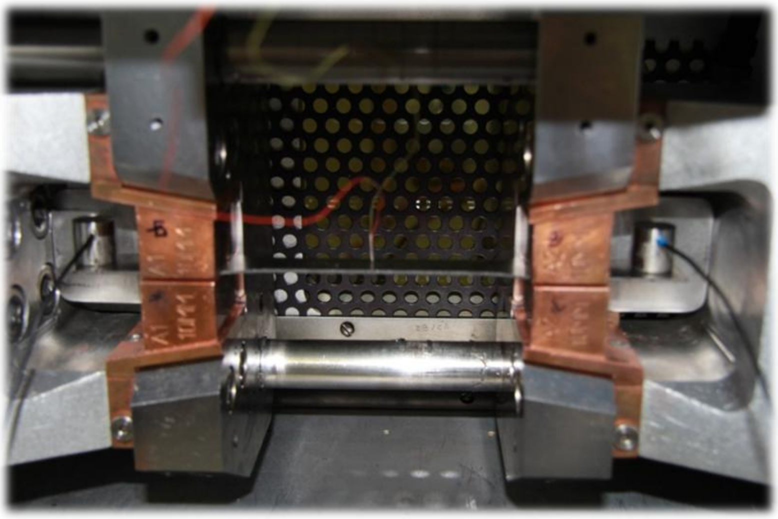

Fig.1. Plate specimen in the Gleeble simulator, where heating and forced cooling took place with two AE sensors behind the current leading jaws

The possible source points of AE were localized along the axis of the plate (see figure 2) according to the differences in arrival time. It is clearly seen from Fig. 2 that there are

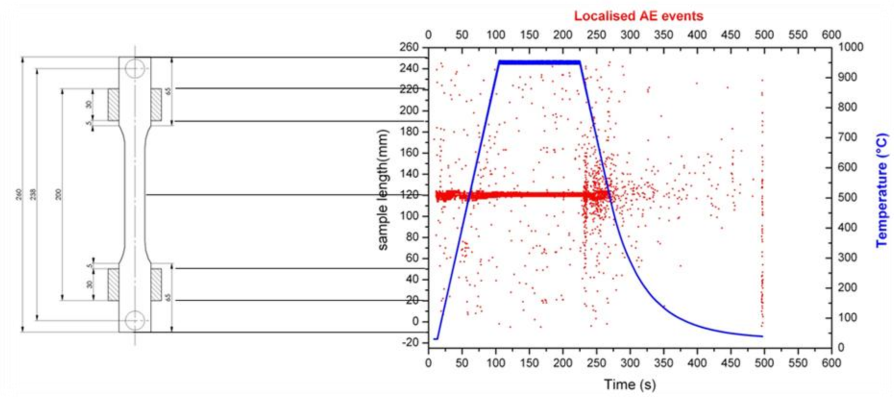

Fig.2. Temperature (blue line) curve and the localized AE events

many events in the middle of the sample but there are two very interesting widening during the cooling period. The middle point were too much to be explained by AE emission in the middle in spite the fact, that the temperature control was made for the middle of the specimen (Fig.1). Partly we thought they could be due to such events which arrived from the background noise for example electromagnetic disturbances from the "air", which hits the two sensors at the same time. But with earlier guards we did not measure such events. Later it turned out they were mainly due to a Barkhausen effect, which we would explained later in details in [8].

We would like to turn the attention of our readers to the AE events during the cooling period. It is a forced cooling with 10^{o}C/minutes at the beginning down to 450^{o}C. After that a natural cooling took place. However, during forced cooling the cooling curve crosses the ferrite transition curve at about 800°C and bainite transition curve at about

500°C (see Fig. 3), exactly where we detected extensive and widening AE events deviating from the middle point (see Fig. 1).

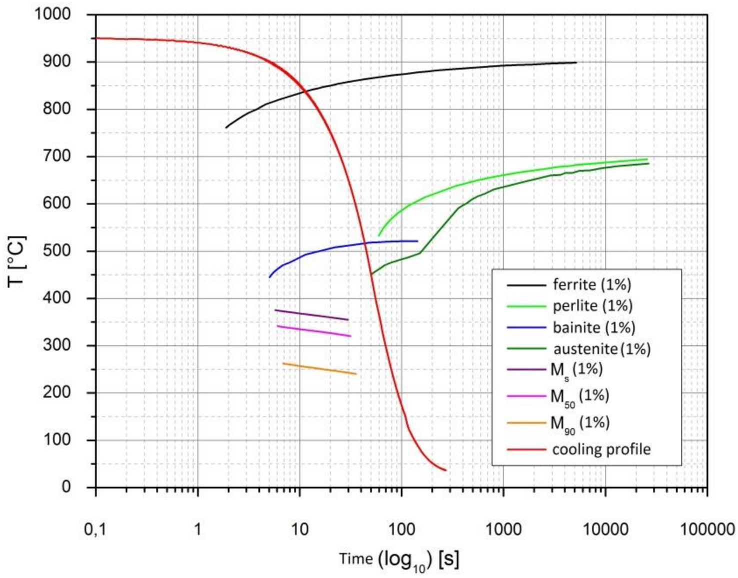

Fig.3 The estimated from measured parameters cooling profile (red line) and its crossing with phase transition lines (CCT curve)

To check the validity of these observations a thorough metallographic investigation was done (see Fig. 4).

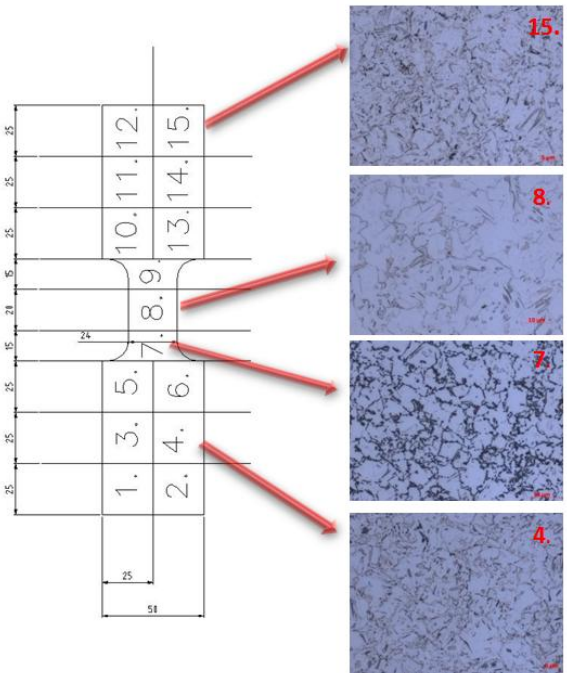

Fig.4. Microscopic analysis of the specimen

The specimen was cut into pieces (see Fig. 4) and after appropriate preparation they were investigated using optical microscope. It is clearly seen that the original microstructure of the material shown on pieces 4 and 15, which were under and behind the jaws of the simulator, has not been treated neither by heat nor by stresses; microstructure change was observed in the middle of the specimen pieces 7 and 8. We have more details to prove that we had phase and structure transitions there. And we believe that this had been registered during our AE measurement.

3. Heat treatment with consecutive tensile test on S235JRG2 steel

In this section we present some of our results of a combined heat and tensile test carried out on a cylindrical specimen made of S235JRG2 steel. That is also ferritic steel. We aimed to see the effect of the temperature change with combined stress on the material.

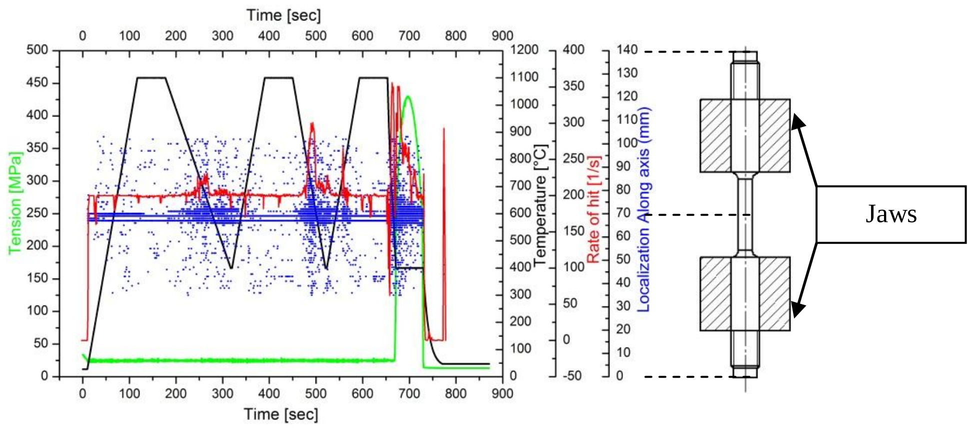

Fig.5. Combined heat treatment and afterward tensile test. After triple temperature (black line) treatment, a conventional tensile test with stress curve (green line) took place until the break of the cylindrical specimen. Red line is the rate of the hits; blue dots are the localized source of AE events

It can be seen on Fig. 5 that during the first three thermal cycles we have got back similar rate of hit curve. Namely, we had strong AE emission in the middle of the specimen with less activity outwards and we had extensive widening during the cooling periods at those temperatures, which corresponds to structural changes in the given material. When the third heat treatment ended we kept the temperature at 400 °C in the specimen and we carried out tensile test, see Fig. 6.

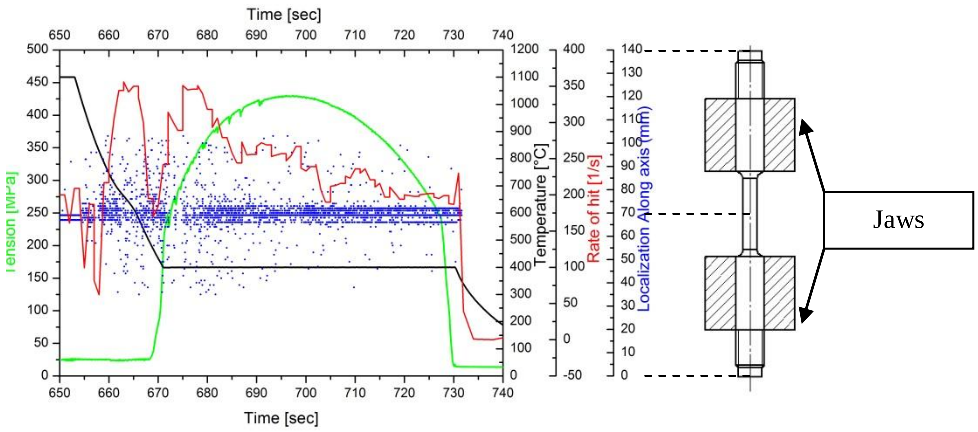

Fig.6. Tensile test part of the combined heat and tensile test investigation (enlarging the end section of the previous figure

Fig. 6 is only the last part of the previous Fig. 5. Here we see more details when after the third thermal cycle the specimen was cooled down. The first peak in the rate of hit (red line) is due to phase transition in the material discussed in previous section. When it had been cooled down to 400 ^{o}C, we kept the material at constant temperature and started the tensile test (see stress curve – green line). During a tensile test typically AE activity is rather large in elastic region and when plastic deformation starts it falls rapidly to almost zero. Not in our case. The rate of hit falls much slower. This could be also due to the heat treatment. But we believe we have here different picture. In the middle of the specimen (blue dots) we have a large Acoustic Barkhausen noise (ABN) activity, which produces constant rate of hit just slightly below 200 imp/sec. That we know from previous figures, that there is ABN at this level. But here we have acoustic activity falling from 350 imp/sec down to 200 gradually. We assume this is due to interaction of dislocations. ABN is caused by domain wall displacement due to magnetic rotation in the material. This enhances the dislocation due to stresses in the material which exhibits in anomalous AE activity in this part of the tensile test.

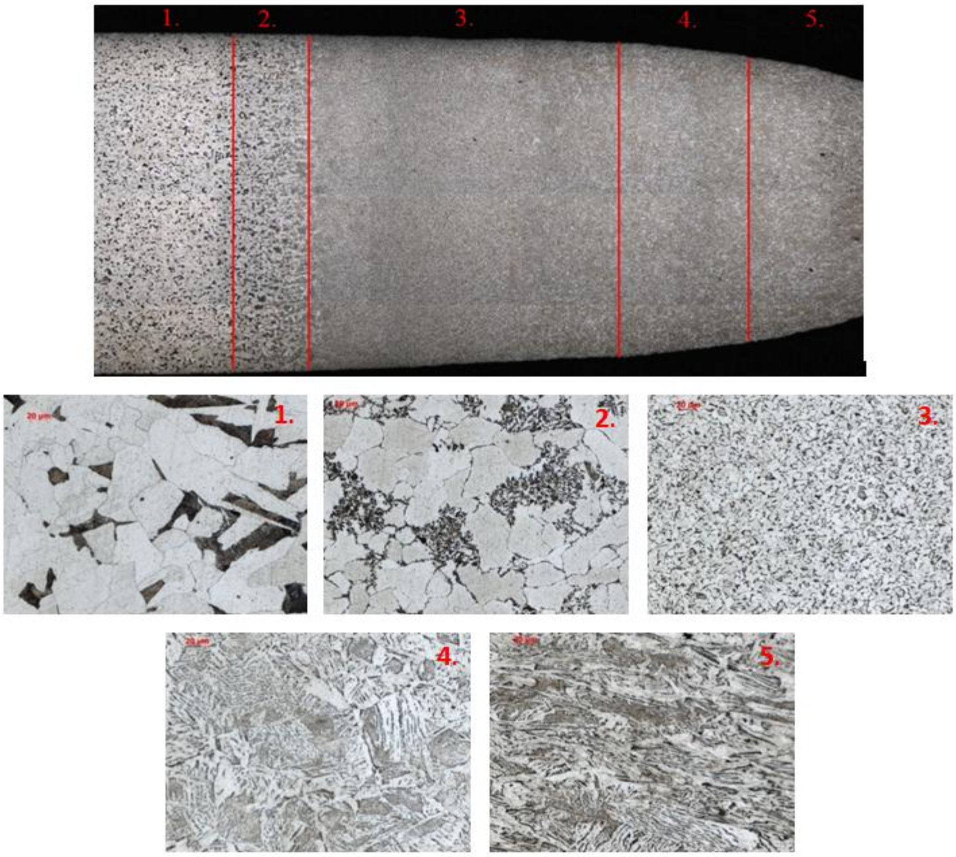

Fig.7. Microscopic structures of the material along the axis after tensile test of heated sample

Naturally we made also metallographic investigations on that specimen. The specimen after the tensile test was cut to half along the axis (see Fig. 7.). It can be seen well, that the structure of the material had been changed very much from the left hand side, where no real change of the structure was supposed to have place till the right hand side, where the contraction shape can be seen, where the specimen was broken. The microscopic structures from 1 to 5 show precisely the change in microstructure of the material. From a coarse grained structure containing rather big cementite structure parts (black) it was gradually refined toward the middle of the material, wherein the heat treatment took place, and finally due to contraction and elongation in the middle aligned structure can be seen on fragment 5.

4. Acoustic Events in a 15H2MFA steel

We investigated this material (15H2MFA) since it is widely used as reactor pressure vessel material in VVER reactors (Russian pressurized water reactors), but similar steels are used also in many other countries. Fig. 8 shows very high ABN activities immediately as the heating (black curve) starts. Naturally, the number of ABN sources (red dots on the right upper picture) is much dense in the middle of the specimen, in the real test section part, since there the current, which causes the ABN, is much higher (due to smaller cross section there).

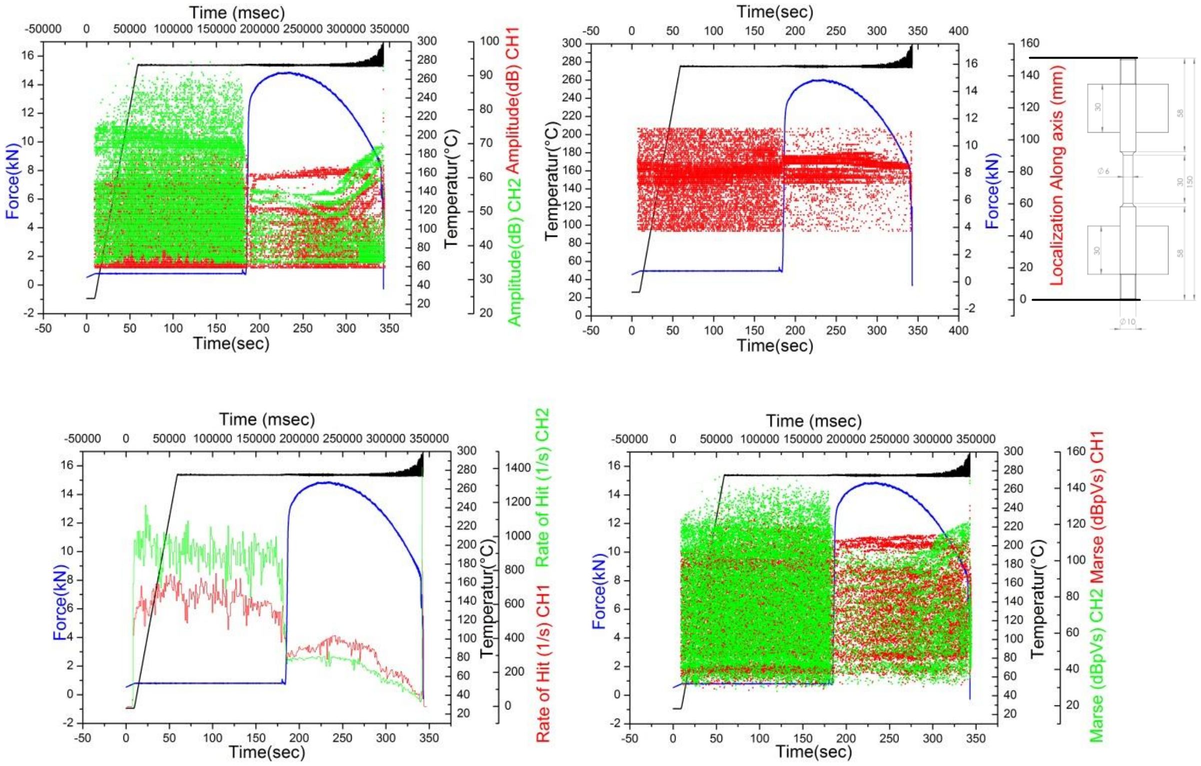

Fig.8 AE results during tensile test on 15H2MFA steel at 260 °C

The real proof of ABN can be found in [8] presented in this conference, where 2MHz sampling was applied during fatigue test in similar circumstances (see details in [8]). With traditional AED-40 AE measuring system we could detect only a train of events on equidistant time of 10 msec (see Fig. 9.)

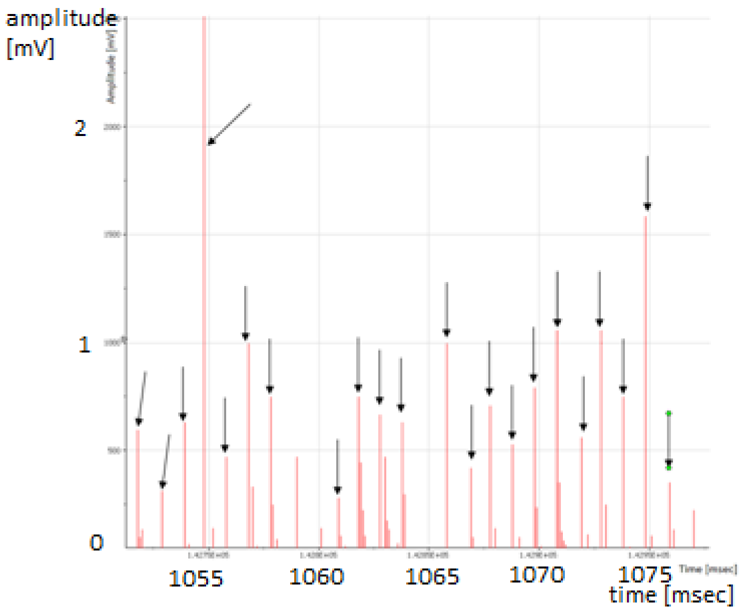

Fig.9. Fragment of detected events by AED-40

The vertical arrows show all those events, which are equidistant for 10 msec (with the accuracy of the event detection of AED-40), while the largest event is deviating from that. It is an additional AE event, which due to dead time prevent the existence of the 10msec ABN there.

5. AE measurement in TWIP steel

Recently, new group of austenitic steels with 15-25 percent of manganese content and 3 percent of aluminum and silicon has been developed for automotive use. The iron-manganese TWIP steels, which contain 17-20% of manganese, derive their exceptional properties from a specific strengthening mechanism: twinning. The steels are fully austenitic and nonmagnetic, with no phase transformation. The formation of mechanical twins during deformation generates high strain hardening, preventing necking and thus maintaining a very high strain capacity. This is today one of the most claimed steel in automotive industry.

Since different stages of TWIP steel during tensile test can typically be divided into segments using the hardening rate we also used this methodology. The hardening rate had been estimated from the stress curve differentiating it and then fitting a spline to that. AE event rate was compared with this hardening rate curve see Fig. 10.

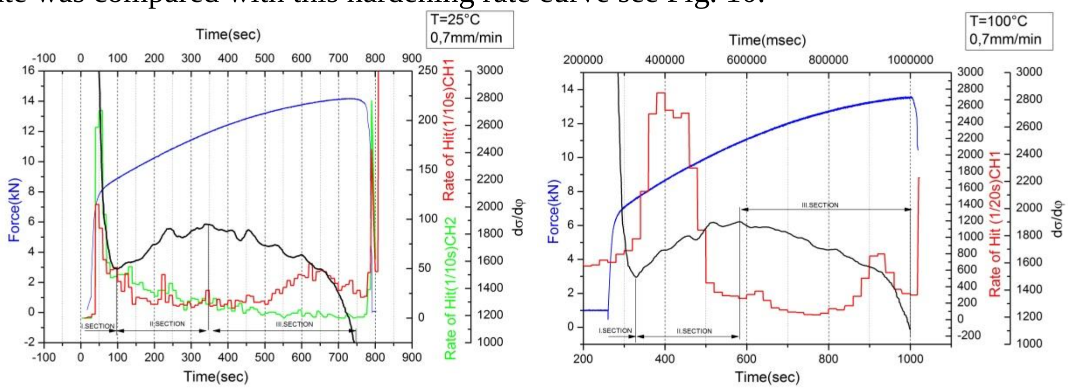

Fig.10. Stress (blue line), estimated hardening rate (black-line) and the rate of hit (red-line) curves at different temperatures

These are just the first results of our investigation on TWIP steels but it is clear that the amplitudes of AE hits are falling with elongation (see Fig. 11)

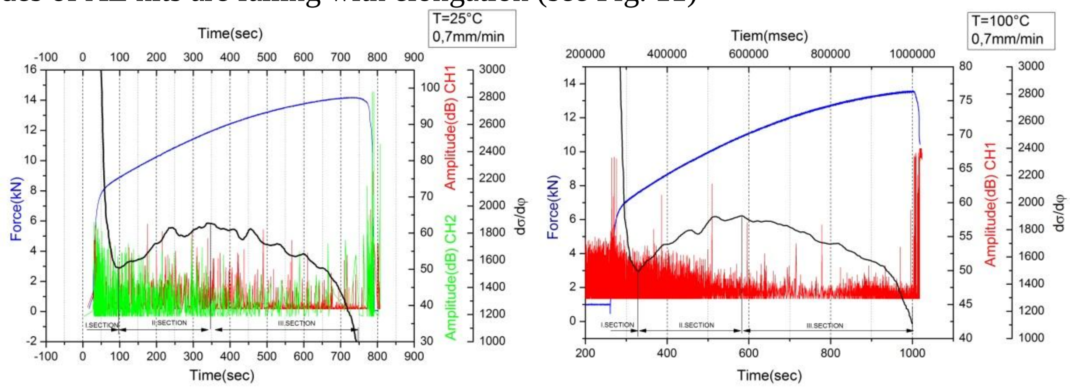

Fig.11. Amplitude of AE events

Conclusions

Acoustic emission measurements were carried out using AE sensors on different types of steels during thermal and consecutive mechanical loading on fixed temperature. It was demonstrated, that there were AE events observed during forced, relatively fast cooling exactly at those temperatures, where bainite transition is supposed to take place in the material. Later metallographic investigation confirmed the estimated fraction of bainite.

However, there have been much more acoustic events observed, than one could suppose, especially at constant, regulated temperature, where the specimen was hold. Detailed investigation of measured signal proved, that the 50Hz AC current heating could be observed in the time signal as series of burst standing periodically at 10 msec from each other. Detailed investigations excluded the electromagnetic parasitic burst transfer, and it was proved by several properties of the burst and their behavior, that they belong to Acoustic Barkhausen Noise. They were produced not by outer magnetic field, but by high AC current, which produced magnetic field that turned magnetic domains producing normal ABN. This interesting effect opened the possibility to use AC producing internal stresses caused by magnetic domain inside ferritic materials.

It was also observed, that during the tension the amplitude of the ABN was inversely to the magnitude of the applied force.

Thus it has been proven; that both the phase transition during cooling may produce AE effect and also current induced magnetic forces can be used for investigation of materials. Collecting enough information in different steels and different effect may lead to understanding what is going on in the ferritic materials.

Our investigations made on TWIP steel is just a beginning of connecting the AE events with hardening process, but it is very promising.

We have started the analysis of the texture and microstructure evaluation of steels under investigation and we hope to get deeper insight of the AE mechanisms based on those structural analysis.

Acknowledgement

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