PROCEEDINGS

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TRACK & STRUCTURES

TECHNICAL SESSION T6

Rail Welding (Rail Joining)

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Optimization of Thermit Welding

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1. INTRODUCTION

The mayor key to a successful aluminothermic welding procedure is an ongoing process of technical development and continual improvement.

The basis for an optimization of aluminothermic welding is an overall consideration of all influencing variables. First of all, the welding process itself needs to be adapted perfectly to the demands. The underlying casting system and the welding parameters used (e.g. preheating system) must fit perfectly to each other in a way that each rail profile and each rail grade can be welded and that the resulting properties of the weld complies to the given requirements.

Secondly, the quality of the products and of the consumables must meet highest requirements as well. Modern production plants and the usage of raw materials with defined properties enable the manufacturing of high quality products and consumables. A well based quality system guarantees the production of thermite portions and moulds of constantly good quality. Statistical Process Control as well as Failure Mode and Effects Analysis (FMEA) are tools that are used to preserve the high quality standard.

The quality of the execution of the weld is very important as well if optimizing a welding procedure. The execution of the weld should be as simple and safe as possible. Nevertheless, a training of the welding personnel is mandatory – most defective aluminothermic welds observed in track can be attributed to human error and not following the given code of practice. Thus, technical support to the customer and to the welding personnel is very important in order to achieve the highest quality of the welding in track.

Of course, customer demands need to be considered, but finally principles of welding and casting techniques have to be considered under all surrounding circumstances during execution of the weld in track.

2. THE OPTIMAL WELD – THE CUSTOMER'S VIEW

In fact it is nearly impossible to answer the question at what stage the technical development of an aluminothermic welding process has reached an optimal or final condition. It is always a question of the point of view how the process and the resulting welds are regarded. This perspective will unquestionably be different considering the customers side and the side of the provider of the welding process.

The basic demands of the customer are

- a robust weld
- a safe execution
- optimal life cycle costs
- an excellent customer support from the supplier
- and a documentation of the welding in track

However, this characterization of the customer requirements is only a general consideration. There are more aspects that need to be taken into account in detail. It has to be decided what kind of aluminothermic welding process could be the best and most robust one for the given load conditions and type of traffic. The demands will be different for light rail, mixed traffic or for heavy-haul operations.

Furthermore, the decision on the best welding process will also be influenced if further boundary conditions are given, e.g. if the gap size is a fixed value in existing guidelines of the railway authority or if a certain pre-heating system is required or excluded for the use in track. Further aspects that could be of importance are favored maximum limits of the preheating time or the demand for a certain type of crucible.

Reliability of a product is another important issue for the customer. The reliability of the welding process, the quality of a weld and its robustness against uncertainly in execution need to be proven. Usually homologation procedures and internal regulations of the railway authorities need to be taken into account before a welding process is allowed to be used in track. EN 14730-1, for example, is an international European standard describing how to approve an aluminothermic welding process.

Safety is important as well. It is self-evident that the given safety instructions must be obeyed. Nevertheless, the welding process itself must be designed for a safe execution. But safety does not only mean that during the execution of the welding possible risks for the welding personnel and for the environment are minimized. Safety does also include that the finished weld ensures a risk-free passing of the trains.

In order to guarantee the safety of the welds in track, the finished weld needs to be checked according to the regulations of the responsible railway authority. After the execution the resulting weld must be free of defects. A visual inspection of the weld as well as non-destructive testing methods can be applied to check the quality of the weld.

Furthermore, the alignment (horizontal and vertical alignment) after final grinding must additionally be measured and must fulfill the demands of the responsible railway authorities.

The inspection of the weld and the results must finally be documented. Today the demand for a more and more detailed documentation comes up. Information regarding location of the weld, welding process, welding parameters and the results of the inspection are basic data that need to be registered. An automatized data acquisition and data storage will unquestionably be an important issue in future.

However, even if the welding process offers a high degree of safety and reliability the quality of the execution is important as well. That means that the welding personnel must be sufficiently skilled and trained to execute the welding according to the given code of practice. But the circumstances in track are many times not ideal. The welder must be trained in a way that he understands the meaning of the individual working steps and that he is qualified to react appropriately on unexpected conditions in track and events during welding. This will ensure that the failure rate will be as low as possible. Nevertheless, nearly all remarkable defects in welds that occur during welding can be attributed to a wrong execution or to unfavorable conditions in track during execution or the bad condition of the track and even the rolling stock.

Consequently, an excellent training of the welding personnel is essential. A trustful relationship to the customer helps to ensure a good technical support. Only a close cooperation with the customer and with the welding personnel makes it possible to get aware of the real problems and demands during welding in track. This knowledge is essential as driving force for the continuous improvement of the welding processes.

Nevertheless, external influencing factors can have a detrimental influence on the weld quality that cannot be linked to the welding process itself or to the expertise of the welding personnel. Unfavorable weather conditions, especially very cold temperatures, as well as a bad condition of the superstructure can lead to an early failure of the weld.

3. THE OPTIMAL WELD – THE SUPPLIER'S VIEW

As producer and supplier of thermite welding consumables and welding equipment the point of view is different compared to the view of the customer. It is the responsibility of the producer to fulfill the customer demands. That means that not only one single customer needs to be satisfied but all customers. Consequently a wide range of welding processes need to be provided.

Welding of flat bottom rails is the most common application for aluminothermic welding. Typically several different welding processes exist side by side based on historical reasons and different market approaches. Visible differences in the welding processes are mainly the casting schemes, the collar geometry of the resulting weld and the preheating parameters. The size of the corresponding thermite portion and its composition are perfectly adapted to the welding process, the rail profile, the rail grade and the type of the crucible used. Using a thermite portion for a purpose other than the one it is designated for may result in a defective weld.

Welding of grooved rails and welding of crane rails are further applications of the aluminothermic welding method. More complex and less often used cases of application can arise during welding of grooved rails for switches and crossings.

Beside the fact that the range of welding processes must cover all different types of rails and profiles it must be considered that different methods of preheating have been established in the market. Most commonly used is a preheating with propane and oxygen. 'Acetylene/oxygen', 'propane/induced air' and 'petrol/compressed air' are further combinations that can be used as preheating media for the aluminothermic welding. However, not every preheating method can unrestrictedly be used in combination with every welding procedure.

Aluminothermic welding is not a new process; it is successfully used since decades. The welding processes prove their quality in a certain way through the usage in track and the existing acceptance by the customers. However, the welding processes are underlying a continuous improvement. This improvement is absolutely essential for a welding process because of the increasing demands of the customer regarding the weld quality, the increasing loads in track and because of the establishment of new standards and regulations of the railway authorities.

One example for an advanced development of an aluminothermic welding process is the HPW (high performance weld) process. This process has mainly been designed for welding head hardened rails and for the usage for heavy haul lines. The special characteristic of this process is that a small container has been attached to the plug which forms the ingate (Fig. 1, 2). This container is filled with alloying elements. During the casting process the alloying elements will be dissolved in the weld metal in the head of the weld. In consequence an increased hardness in the head compared to the hardness in the web and the foot is achieved. This selective alloying system results in a weld with improved mechanical properties and makes it more suitable for heavy haul applications (high wear resistance of the head; ductility and better fracture toughness in web and foot).

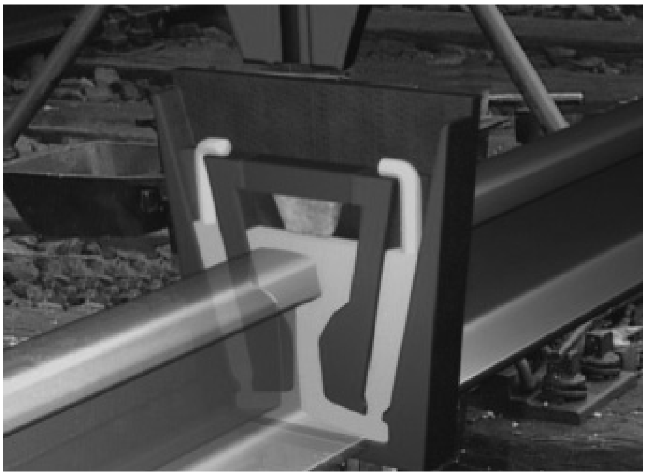

Figure 1 : schematic presentation of HPW welding process

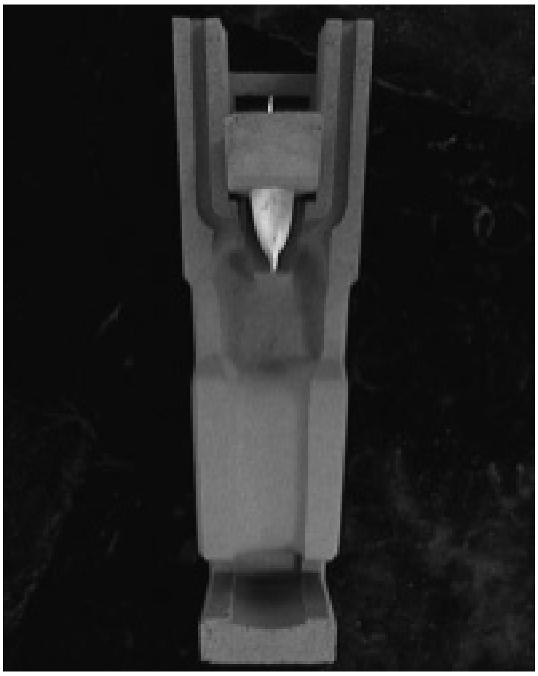

Figure 2 : HPW mould and plug

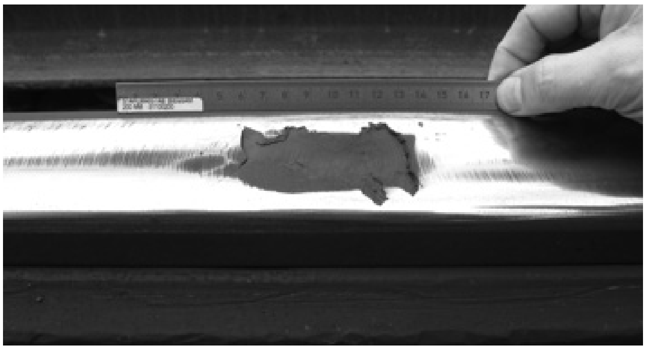

Figure 3 : squat

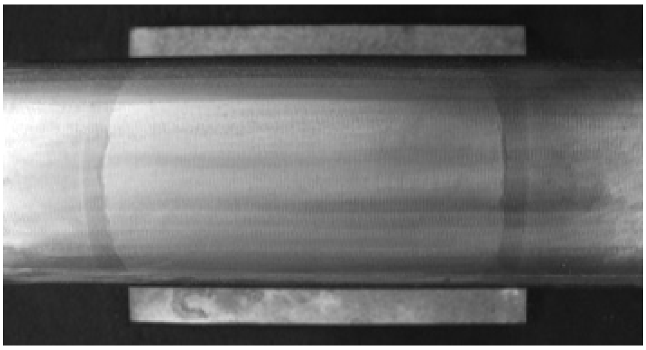

Figure 4 : THR weld, view on running surface

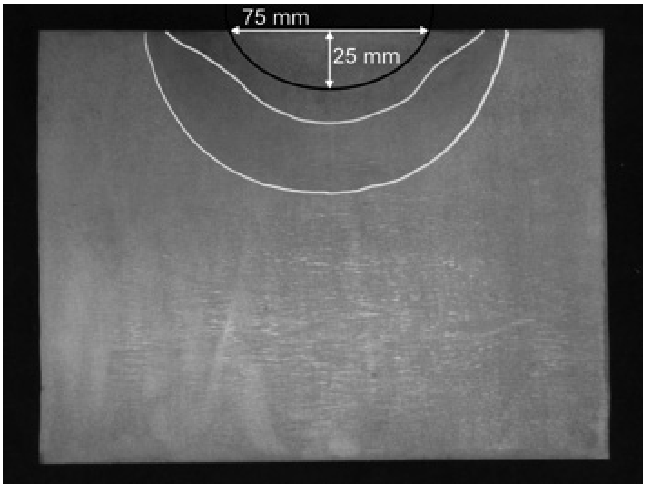

Figure 5 : Longitudinal section of THR weld, shape of excavation and fusion zone and HAZ

Another advantage is that only one type of thermite portion for a given rail profile is required. The grade and hardness of the weld is adjusted with the corresponding plug. Thus, this system offers an improved and more simplified logistic for the customer.

Another adoption of the thermite welding technology to the demands of the customers is the THR process (Thermit® Head Repair). Defects on the running surface of rails like squats (Fig. 3) can be repaired (Fig. 4). However, only single defects of limited size can be removed with this process. The excavation in the rail head has a length of about 75 mm and a depth of about 25 mm (Fig. 5). These dimensions enable to repair most defects that can be found on the running surface. The THR process is generally very similar to the known thermite welding of rails and allows repairing without setting a plug and the neutralization of the track – this safes money and track time. The properties of the THR weld regarding the running surface are therefore comparable with those of a wide gap weld.

As mentioned before, the quality of a thermite welding process und the applicability of the process are given automatically if the process has proven its reliability in track already for many years. Nevertheless, an excellent performance of a welding process can be based on methods of development that had been old-fashioned and mainly based on an intense experimental testing.

That does not mean that a new development of a welding process needs not to be tested in detail in the laboratory, but nowadays new technologies and methods are available that make a development of a welding process more efficient. A deeper understanding of the process can be gained. Consequently improved aluminothermic welding technologies can be developed.

Of course, one of the new techniques for the development of aluminothermic welding processes that can be used today in a much more efficient and faster way are simulation methods. An all-embracing simulation of the complete welding process is quite difficult. Generally two working steps need to be differentiated for thermite welds, the preheating and the casting process together with the following solidification.

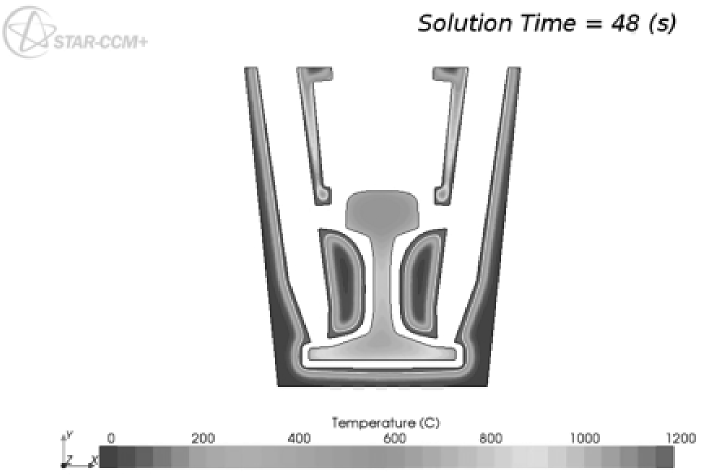

Figure 6 : Calculation of temperature distribution during preheating

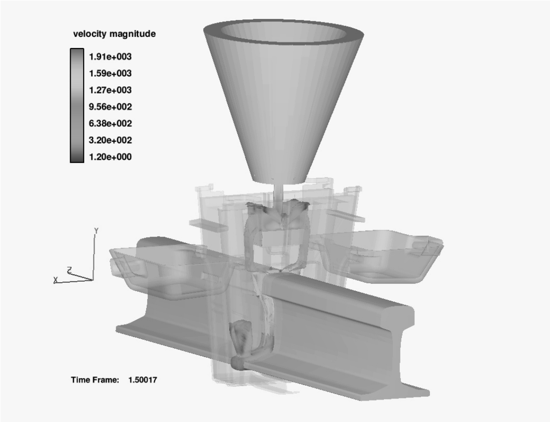

Figure 7 : Calculation of velocity of ingating steel during casting process

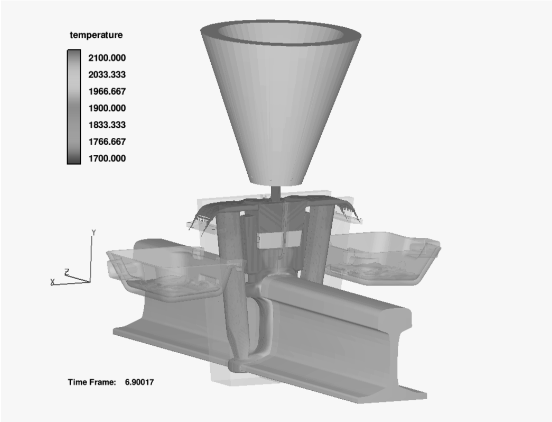

Figure 8 : Calculation of temperature of ingating steel during casting process

An example of a calculated temperature distribution during preheating is given in Fig. 6. This result is based on a preheating with propane and oxygen. It is self-evident that a very precise temperature measurement has been necessary beforehand. If executing such a calculation it must be clear that it is only a single result for one regarded welding process and rail profile. However, it is possible to achieve a better understanding of the preheating process and it is possible to give a good prognosis if any of the given boundary conditions of the simulation are changed (e.g. the geometry of the moulds).

The casting process is the second important working step that can be simulated. A clear view how the liquid steel is filling the gap make it possible to draw further conclusions with respect to the regarded welding process. It is obvious that this kind of simulation is a very helpful tool for the development of welding processes, but it must be understood that the real ongoing processes cannot be completely calculated. There are still limitations given; the final shape and the dimensions of the fusion zone cannot be displayed up to now. A simulation of the resulting microstructure of the weld metal is also hardly possible.

Nevertheless, by using simulation tools it is for example possible to optimize the preheating system. The temperature distribution can be calculated regarding the cross profile of the rail and the minimum required heat input into the rail can be assessed. By this the process parameters as well as the preheating equipment and the portion for aluminothermic welding can be optimized.

Thus, simulation tools and a deeply based know-how of the processes during aluminothermic welding make it possible to improve the processes step by step. The geometry of the moulds is one key parameter for a successful performance in track. The second important key parameter is the quality of the thermite portion.

It is well known that the aluminothermic process is based on a chemical reaction between aluminum and iron oxide. Obviously a thermite portion does not only consist of these two components. Further components need to be added to give the resulting weld metal the required properties. In order to achieve a thermite portion and a thermite weld of highest quality an intensive quality control is required. All components of a thermite portion need to be clearly specified and controlled with respect to the relevant properties, like chemical composition or particle size distribution. Additionally, the thermite portions produced for the customer need to be checked as well. The quality management system clearly defines in what manner and in what frequency test welds need to be executed. Naturally, all resulting quality data are recorded and stored in a corresponding data base and enable to find correlation between them.

However, that kind of statistical process control can have an additional value, if the available data are used for an enhanced analysis. For example, a regression algorithm has been developed based on more than 10000 measurements. The chemical composition of the weld metal has been used to conclude on the actual hardness of the weld. Thus, if a chemical composition of the weld has been measured the real hardness can be predicted within a given range (Fig. 9, 10). It can be seen that the calculated and the measured hardness values are in a very good agreement. The advantage of such an analysis is that, if a remarkable deviation between both values can be observed, a hint on a possible nonconformance of the product or the process is given. Furthermore, in case of a failure analysis of a defective weld the measured chemical composition can hint on the hardness of the weld.

The failure mode and effects analysis (FMEA) is another tool that is used for the development of the welding processes and the products. There exits many influencing factors on the welding process and on the quality of the products. Aim of the FMEA is to identify these influencing factors and possible failures, to assess their detectability and their severeness and to find corresponding corrective actions. Thus, the purpose of the FMEA will be to reduce the amount of influencing factors or to reduce the spread of a characteristic property of the product or of the weld (Fig. 11, 12). This will give much higher process reliability and a higher safety if a deviation of that characteristic property from the mean value can be observed.

Today the final products need to be subjected to a much more intense quality control than in the past. In order to check the product with respect to the increasing demands the experimental efforts to execute the corresponding tests rises drastically. In order to keep the related quality costs as small as possible other possibilities need to be found. The successful usage of the statistical process control and the usage of the FMEA method allow keeping the quality costs low. Consequently, this allows to keep the price of the product low.

The third key parameter that is essential for the quality of the weld in track is the quality of the execution. However, basis for this is that the welding process and the required

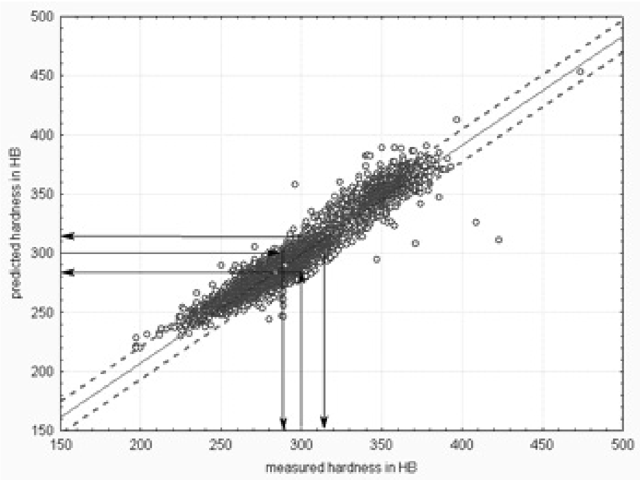

Figure 9 : Calculated hardness against measured hardness

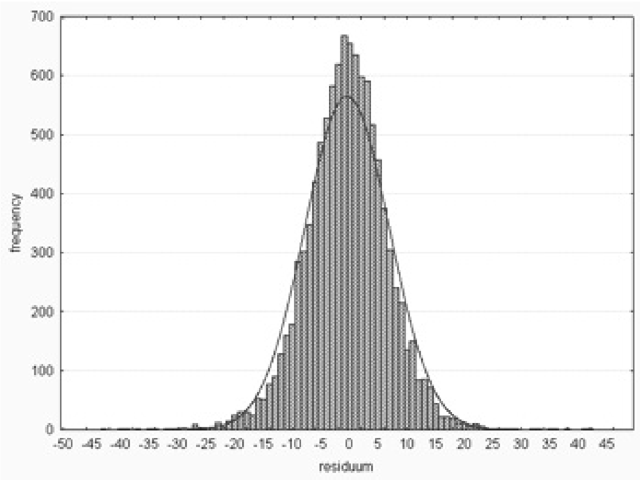

Figure 10 : Residuum; difference between measured and calculated value

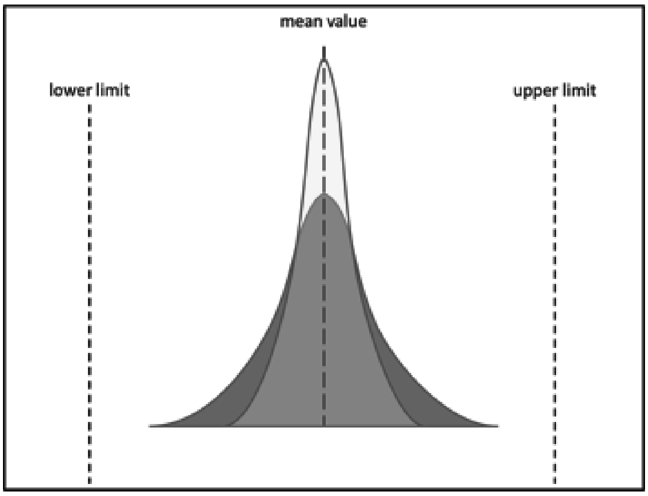

Figure 11 : Optimization of a characteristic property of the product

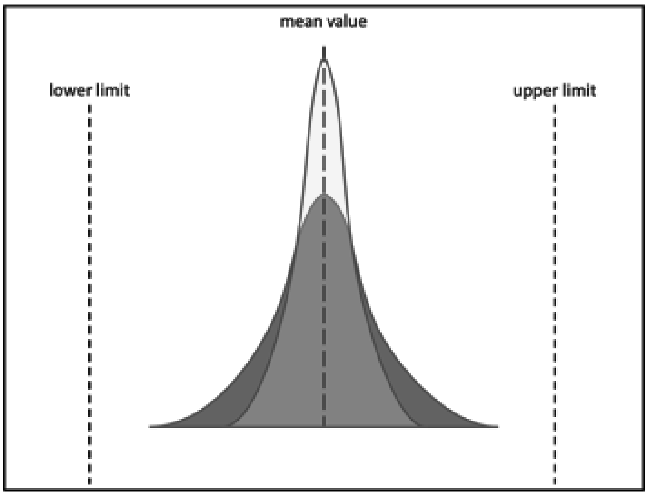

Figure 12 : Improved distribution gives more safety if deviations from mean value occur

consumables (thermite portions and moulds) are of excellent quality and the used welding process is the best one for the existing load conditions in track. Achieving the best quality of the weld in track means that the welders are well-trained.

Sufficient time for the execution is another important issue, because overhasty work will lead unavoidably to errors in the execution of the weld. Nevertheless, the condition of the superstructure is important as well. Breaks of welds might occur if the superstructure is in a bad condition even if the weld has been executed in a perfect manner.

If everything works fine the rate of weld breaks is quite low. In Europe and Asia this rate is between 0,01 % and 0,05 %. This shows that a very good performance of Thermit® welds in track is possible. In heavy haul lines the loads are much higher. Thus a higher rate of weld breaks can be expected. However, reliable data regarding the number of weld breaks in track and the reason for the breaks are hardly available. And there might be an estimated number of unreported cases. Thus there is room for improvement especially by using HPW and THR.

4. CONCLUSIONS

It is undoubtedly recognized that a well-engineered welding process in track is required to ensure a safe and robust weld. These welds must be reliable and robust enough in a way that small deviations from the code of practice or any other external influencing factors can trouble-free be compensated. The quality of the weld and the safety in track may not suffer from an oversensitivity of the used welding process.

The quality of the weld is dependent on

- the quality of the welding process
- the quality of the consumables and
- the quality of the execution.

Notwithstanding is the quality of the superstructure an important issue as well.

If the superstructure is in a good condition and if the welds are executed correctly the resulting failure rate in track becomes very small.

This failure rate will increase,

- if the condition of the superstructure diminishes
- if the load in track increases
- if the execution of the weld is bad
- if the welders are not trained

Even if there is a reliable and robust welding process there are some factors that can have an influence on the weld quality. Some of those influencing factors can be controlled; some of them cannot be controlled. Each single deviation of the code of practice or every single external factor is supposed not to have a negative influence on the weld quality. Only if the sum of influencing factors has reached a critical limit weld defects or weld breaks may occur.