BELENUS

Lowering Costs by Improving Efficiencies in Biomass Fueled Boilers: New Materials and Coatings to Reduce Corrosion

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Executive Summary

This deliverable aims to review data on welding and bending of coated steels and to outline the scope of the work that has to be carried out in work package 5.

The available literature for welding of coated materials is very limited but that which is mainly relates to galvanised steels where the evaporation of zinc is problematic. Private works conducted by some partners, and considered prior art, suggest that the coating to be used within this project can be welded without serious damage being imposed on the coating.

Whilst there is significant literature on the effects of cold work on the substrate alloys to be used in the project there appears to be no public literature on the effect of cold work on coatings, with regards the mechanical integrity of the substrate. There are two main areas of concern namely creep strength reduction, particularly for the ferritic alloys, and strain induced embrittlement, particularly for the austenitic alloys.

This deliverable, in conjunction with D1.4 “Testing Matrix” scopes out the work to be conducted in Work Packages 3 and 5.

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1. Content of Deliverable

The aim of Task 1.6 is to produce the scope of the welding and bending investigations. The participants of the task (TUM, DBL and RWE) will assess the data base accessible and outline the work that will be done in work packages 3 and 5. The strategy of joining coated tubes will be discussed, specimen geometries for different experiments will be suggested.

2. Data Collation

2.1. Welding of coated steel

Due to the novelty of the approach, the authors were not able to identify many references in scientific or technical literature that deal with the welding of coated tubes.

The website of *Total Materia* published an article in 2006 about arc welding of zinc-coated steels [1]. The authors state, that zinc-coated steels can be welded, if specific precautions are taken. The challenge of welding these materials lies in the vaporization of the zinc due to the heat of the weld arc. Since zinc has a lower boiling point (871°C) than the melting point of steel (1540°C) the zinc will leave the base material adjacent to the weld. The extent of coating disturbance depends on the heat input of the arc and the heat transfer in the base metal. Furthermore, the vaporizing zinc may be entrapped in the molten metal which can lead to porosity in the weld metal after solidification. In addition, the presence of zinc in stressed welds may lead to the formation of cracks or delayed cracking due to stress corrosion. This risk can be minimized by a joint design that allows the zinc vapor to completely escape from the weld pool. Another precaution is to use sufficient heat input, so that the weld pool does not solidify too fast to allow the zinc vapor to escape. The authors stress that it is important to secure complete and full penetration of the joint. At the same time, they also state that in order to completely avoid these challenges, the coating should be removed from the area of the weld joint.
The authors give a detailed list of things that should be considered during the arc welding of this type of joint. They state that the selection of the welding electrodes should be based on the size/thickness of the material and the welding position. Slow travel speed to allow the degassing of the molten metal and a forward pointing electrode to force the zinc vapor ahead of the arc are advised to achieve good quality joints.

The Fabricator also addressed the arc welding of coated steels in 2005 [2]. The author of the article states the challenges of welding such joints lie in high levels of spatter and welding fume, weld porosity and poor bead shape and the formation of cracks in the welded joint. It is stated that the increased amount of spatter is a result of the vaporizing zinc that leads to instability of the weld arc. The article describes the adjustments that have to be made with regards to the filler metal wire diameter, welding speed, shielding gas composition etc. to improve the quality of zinc coated steel welds.

For aluminized sheet steel welds, it is stated that different challenges arise, which are easier to handle compared to zinc coated steels. Control of bead shape and spatter levels are key issues which stem from the formation of difficult-to-remove oxides that interfere with bead wetting and generates arc instability.

The Welder offers a short article about welding of aluminized steel from 2014 [3]. The author points out several considerations that have to be taken into account from a practical point of view.

Narayanan et al. explore the welding of zinc coated steels in a scientific manner [4]. They provide a broad overview over different process solutions for joining galvanized steels in the automotive sector. Three major challenges with welding zinc coated steels are mentioned in this article: high spatter amount, poor bead appearance and high internal porosity. Furthermore, the residues left on the surface after welding pose problems for the corrosion resistance by interfering with the re-application of the coating after welding. The authors propose novel strategies to join zinc coated steels. One strategy proposed deals with the intentional alloying through the core of a filler wire to affect zinc evolution time, the other strategy discusses a welding process that uses an advanced power source to enable stable droplet transfer using an AC waveform to enable a filler wire to be used at high travel speeds without affecting critical weld attributes.

2.2. Bending of power plant steels

With regards to the bending of the materials, the effect of cold work and post-bend heat treatment on elevated temperature rupture properties of grade 91 material (9wt.%-Cr creep strength enhanced ferritic steel) was investigated by a research group led by EPRI in 2005 [5]. It was found that the strain induced by cold bending has a significant and adverse effect on the creep rupture strength of grade 91 material. It appears that there is no threshold value below which the effect is absent. However, the magnitude of the effect increases with the level of cold-strain induced. Furthermore, the group found out that a subcritical post-bending heat treatment provides no benefit with regard to restoration of the creep rupture strength - another study even suggested that in some cases the post-bend heat treatment may have a damaging effect. Due to the cold bending, an increase in the hardness of the material was documented, which is proportional to the amount of strain applied. The tempering effect of the post-bend heat treatment was able to reduce the hardness induced by strain to levels that compare to the base material. The group was surprised to find a possible relation between the magnitude of the creep life reduction and the increase in the material hardness caused by the cold work (see figure 1).

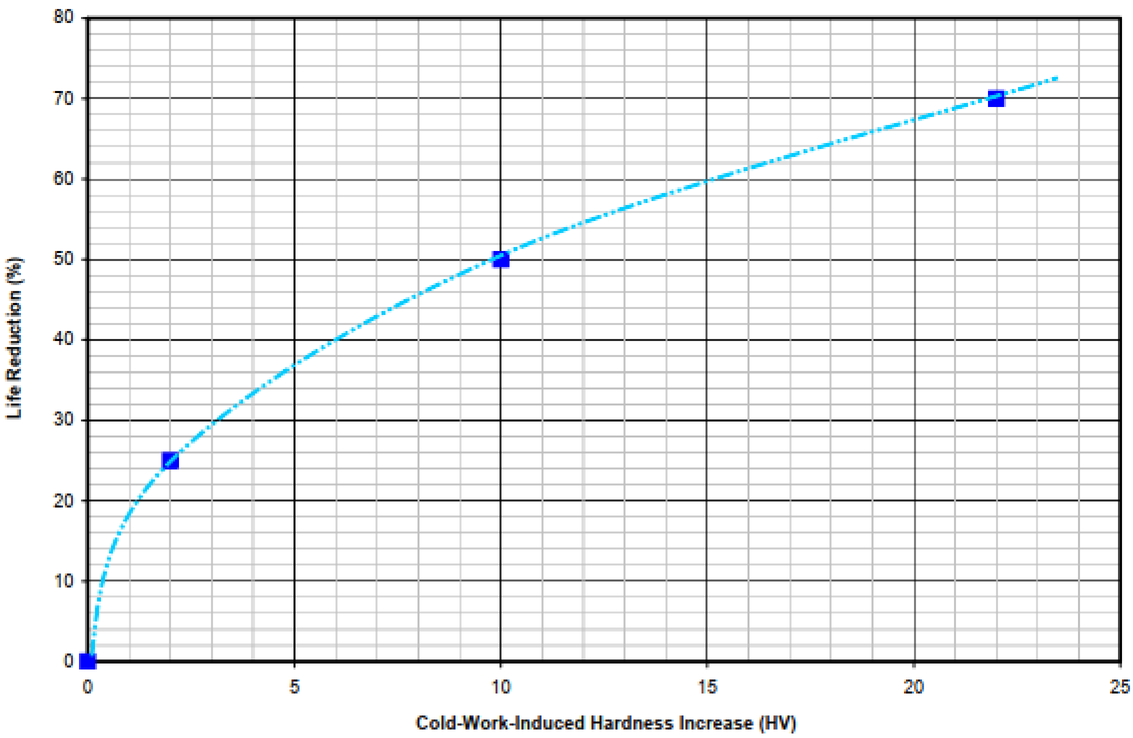

Figure 1: Creep life reduction as a function of hardness increase induced by cold-working.

The investigators recommend that if the full strength of the Grade 91 material is required to ensure satisfactory service life, then when the amount of tensile strain induced during bending exceeds 20%, the full length of the tubing should be renormalized and tempered.

Another technical report under the lead of EPRI from 2009 deals with the strain induced hardening of stainless steels [6]. It is stated that under certain conditions, a metallurgical phenomenon named strain induced precipitation hardening (SIPH) of stainless steels can occur. If a stainless steel component is subjected to straining (cold or warm) prior to application, and then is subsequently put into operation at elevated temperature SIPH may lead to accelerated material degradation. The cold working of the material leads to decreased ductility, while strength and hardness are improved, since alloying elements such as Nb, Ti or N will precipitate at grain boundaries. Putting cold-worked components into temperature ranges of the creep regime, premature failure may occur. In a newsletter on the website of *David N. French Metallurgists,* the mechanism for premature failing was explained as follows: "*In solution-treated materials when a grain-boundary creep crack develops, the growth or extension of the crack is slowed or blunted by the soft and ductile neighbouring austenite grains. The deformation energy of the movement of the grain boundary crack is converted into plastic deformation in the crystals preceding the crack. In cold-worked material, the ability of the austenite grains to blunt the crack growth by energy absorption is diminished. Cold-worked grains are less ductile and can no longer "bend" to prevent further crack movement.*" [7] SIPH is a failure mechanism associated with cold work of austenitic alloys. Cold work induced an extensive dislocation network within the grains with the close linking dislocations acting as preferential secondary precipitation sites. If the service temperature is low, the precipitation rate is to slow to be of significance. If the temperature is high, dislocation movement reduces the precipitation sites. At intermediate temperatures, intragranular precipitation results in grains that are resistant to deformation. Grain boundary precipitation of secondary particles consume the near grain boundary precipitate, i.e. a grain boundary denuded zone. These weak zones then concentrate at deformation within a narrow zone along the grain boundary resulting in a low ductility failure mechanism [8]. These references agree, that a solution annealing treatment subsequent to cold- or warm-working reduces the hardness and returns mechanical properties to those in the as-received condition and can reduce/eliminate the deleterious effects of SIPH.

3. Definition of future work scope

The data collation shows the rarity of references with regards to the welding of coated steels, in particular coated creep resistant steels. This highlights the scope of work to be carried out in the BELENUS project as novel approach in the application for electric power generation.

However, from the scarce literature available it is expected that we do not face the same challenges in welding coated tubes as described for zinc coated steels. As far as it is possible to tell now, there should be no problems with vaporizing elements that could destabilize the welding process. It will be more important to investigate the tolerance of intermixing of the coating with the weld metal and its influence on the mechanical and corrosion properties of the welded joint. For example, the dissolution of Al-based coatings might lead to the precipitation of Al-rich precipitates, such as Al-nitrides and therefore have an influence on high temperature mechanical properties.

3.1. Welding investigations/strategies

Since the limiting factor for the lifetime of the tubes will be the fire-side coating, we suggest to use an oxidation resistant weld filler material such as Ni-based weld electrodes. With this kind of filler material sufficient steam-side oxidation resistance in the vicinity of the weld should be achieved. Therefore, it is not necessary to re-coat the inner wall of the tubes after welding. However, for the fire-side outside wall a re-coating of the missing coating after welding will most likely be necessary to guarantee proper corrosion resistance of the coating. The lab experiments will give insight on the fact whether the outer coating needs to be removed in the weld area prior to welding or if it is sufficient to keep the outer coating as it is.

The thermo-mechanical welding and forming simulator Gleeble will be used for pre-examination of the welding and bending behavior of uncoated and coated specimens. For the uncoated samples, the specimen geometry is shown in figure 2.

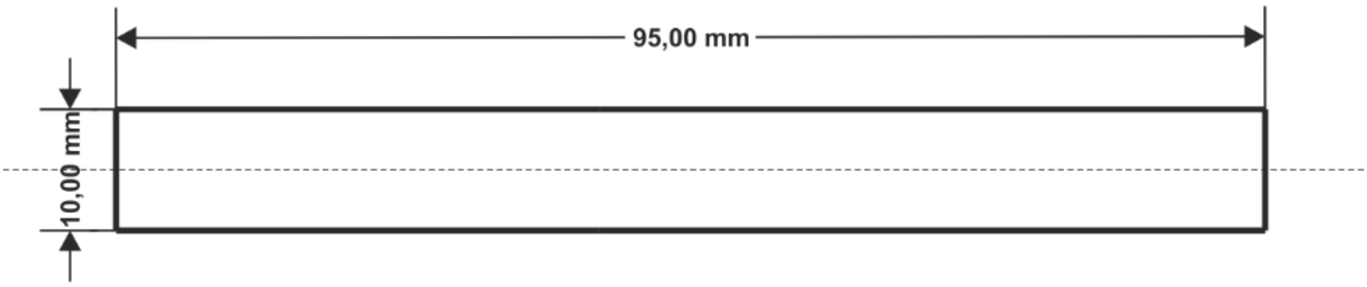

Figure 2: Specimen geometry for thermo-physical simulation experiments using the Gleeble system.

This geometry would be preferred for coated samples too. For slurry coating, this should be possible. However, during the 2nd GA meeting partners responsible for the application of the fire-side coating voiced concern that they would not be able to produce this kind of sample geometry. In case it would be impossible to produce such samples, it is suggested to produce flat specimens (refer to figure 3 for an example).

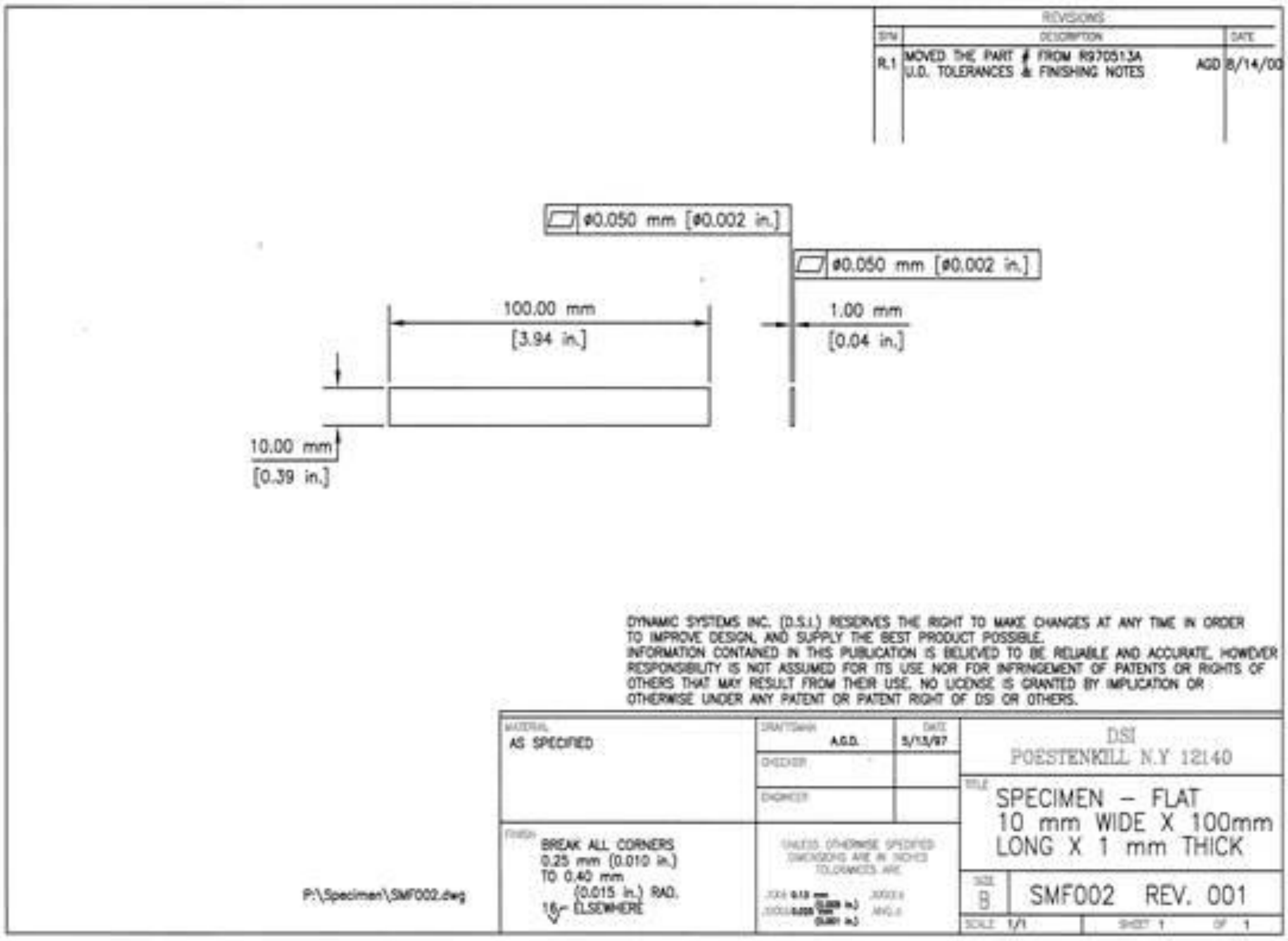

Figure 3: Example of the sheet sample geometry for the use with the Gleeble system.

For the welding experiments, we suggest to use coated and un-coated sheet steels, since sheets should be easier to prepare for basic welding experiments and the sheets should be easier to handle with regard to coating them. If sheet material is available, uncoated sheet pieces would be used to determine the welding behavior of the base metal with the dissimilar Ni-base weld filler metal and to gauge proper welding parameters to optimize the welding process. In the second step, these parameters will be used on coated sheets. Here it should suffice to only coat one side of the sheet, so that two sets of specimens are prepared – one set with the steam-side coating and another series with the fire-side coating. With these experiments and the subsequent metallographic investigation, we are able to determine the degree of intermixing of the base material, the coating and the weld filler metal. Once sufficient progress is made and the effect of intermixing on the welded joint is investigated, it is planned to apply the findings to the welding of coated tubes.

3.2. Bending investigations

The bending tests that are supposed to screen the coating systems specified in D1.4. Coated coupons are deformed/bent over a radiused mandrel, straining the substrate and coating. Using a range of mandrels with differing radius allows the definition of maximum strain allowable before coating cracks occur In addition to these tests it is possible to conduct compression tests utilising the Gleeble system. For these tests, cylindrical samples with a diameter of 10 mm and a length of 15 mm are needed. Again it is necessary for the partners in charge of coating the material to assess whether it is possible to produce those samples.

3.3. Post weld/bend heat treatments

As the data collation showed, cold-working will definitely affect the base tube material. If the maximum strain gets too high, a post bend heat treatment (PBHT) needs to be applied in order to keep the creep properties of the base material at a sufficient level. It is necessary to keep in mind that this heat treatment will most likely apply temperatures ranging from 900-1100°C to the base material. The coatings need to withstand this temperature for up to 2 hours (depending on the base material). Unfortunately, this heat treatment cannot be conducted in a sub-critical temperature range, as the references given earlier, state that sub-critical heat treatments have no positive impact on the creep properties of the base material.

To produce proper weld joints with sufficient mechanical/creep properties, also a post weld heat treatment (PWHT) will be necessary. However, for most of the base materials the PWHT temperature should not be as high compared with the PBHT and would only affect the area of the weld joint.

4. Dissemination Level

Public.

5. References

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