Residual Stresses and Near-surface Material Condition of Welded High Strength Steels after Different Mechanical Post-weld Treatments

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ABSTRACT
Investigations on high strength steel S690QL butt welds with different mechanical post weld surface treatments have been carried in order to show how different treatment intensities are interacting with the near surface residual stress condition and at least with the resulting fatigue strength. Experiments with high frequency hammer peening techniques in comparison to shot peening processes reveal, that the penetration depth of the induced compressive residual stresses is higher after the application of the hammer peening processes. However this does not necessarily lead to the best residual stress distribution because high intensities may also produce detrimental tensile residual stresses in deeper surface layers. Finally the results show, that the combination of different measurement techniques enables a reliable characterization of such treatments.

INTRODUCTION
Many efforts have been realized in the last three decades to develop methods for a fatigue strength improvement of welded constructions [Heeschen 1986, Müsgen 1982, Maddox 2004]. This is due to the well known effect that the fatigue strength of welded steel and aluminium joints usually is very low after welding in comparison to the base material. Thus the usage of modern materials like fine grained high strength steels does not lead to remarkable improvement of the fatigue strength under alternating or partially tensional loading conditions if the same welding procedures are used. As many investigations have shown a post weld treatment with help of thermal or mechanical treatment methods can be very helpful regarding to the final fatigue strength. Target of the REFRESH-project, which is supported by the German Federal Ministry for Education and Research (BMBF), where the presented investigations are related to, is to develop strategies which allow a significant extension of the fatigue endurance of welded steel constructions like bridges or the supporting structures of wind energy plants. The beneficial effects of easy to handle post weld treatment techniques shall be used to generate surface hardening and compressive residual stresses in order to extend the life time of such constructions. It is well known, that the benefit of mechanical improvement techniques depends on the combined effect of an increasing hardness due to cold working of the surface, on the magnitude and the distribution of near surface compressive residual stress and on the reduction of local load stress concentrations due to a cold forming of the weld toe. Each of the available treatment techniques has certain advantages, and the results which are summarized in literature do not reveal, that a certain method will lead to the best results under any condition.

Many investigations have shown that post weld treatments which are generating compressive residual stresses are more effective in welds which are loaded under reversed bending [Haagensen 1987, Sonsino 2004, Wohlfahrt, Krull 2000]. In this case the treatment is the more effective, the lower the plate thickness is or the higher the depth of penetration is. Therefore many efforts are made to increase the intensity of mechanical surface treatments in order to maximize the amount of the compressive residual stresses as well as the penetration depth. Due to the strongly increasing energy costs, weight reduction becomes more and more important. On the other hand many steel constructions like bridges or the platforms of wind energy plants will achieve or exceed their design lifetime limits in the next decade which has a great economical importance because many efforts and costs would be required to replace such buildings. Here the application of post weld treatment methods principally offers the possibility to exceed the calculated life time in cases, where no fatigue cracks have been generated until now or where such fatigue cracks and their consequences can be eliminated by local treatments. That is the reason why actually many new investigations are concerned with the possibilities of different post weld treatment methods.

INVESTIGATED MECHANICAL SURFACE TREATMENT PROCEDURES
In this Investigation three processes are observed. These are the classical shot peening process which is a state of the art method for many industrial applications and two relatively new hammer peening procedures. These are an air pressure driven hammer peening process (HiFIT) and a process where the excitation of the tools is realized by means of ultrasonic waves (UIT). The characteristic feature of both processes is, that the working frequency of the tool which is cold forming the surface, is very high in comparison to older hammer peening techniques. Both methods use a frequency of approximately 200 Hz. This surface treatment with a high intensity leads to strong plastic deformations concentrated at the weld toe. Beside the generation of residual stresses and the cold hardening of the surface the treatment is connected with a deformation of the treated zone, e.g. the weld toe. This results in a shape of the weld toe after the treatment which is related strongly to the shape of the tool, and that is to say the weld toe radius after the treatment is very similar to the radius of the tool tip. Because this radius usually will be much higher than the weld toe notch radius after welding the stress concentrations at the weld toe may be lowered with a beneficial effect with regard to the fatigue strength. Preliminary investigations (IIW-Doc XIII-2099-06) have shown, that the geometry of the weld toe after the treatment is very important with regard to the crack initiation as well as to the fatigue strength. In relatively soft materials like aluminium alloys a too high intensity of the treatment can produce overlaps or material undercuts as a consequence, that the beneficial effect of the residual stresses and the increased hardness is canceled partially by these new geometrical

269