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DEEP ROLLING EFFICIENTLY INCREASES FATIGUE LIFE

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ABSTRACT

Deep rolling is a manufacturing process that efficiently increases the fatigue life of dynamically loaded components. It combines three effects to enhance fatigue strength, tribological properties and corrosion of a surface. Deep rolling

- Smoothes the surface
- Induces deep compressive stress in the surface zone
- Work-hardens the surface zone

The technology has developed into a modern, widely applicable process that improves part performance and achieves lightweight design. It has successfully been applied on stainless steels, alloy steels, brass, tool steels, nickel alloys, cast and ductile irons, aluminum, magnesium and titanium alloys [1,2,3].

INTRODUCTION

The surface zone of a workpiece has a vast influence on the strength of a component, especially one under cyclic load. Material scientists continue to investigate the correlation between surface zone properties and fatigue strength. We know today that surface finish, residual stress and microstructure are important parameters for optimizing the surface zone. Almost any manufacturing process influences these parameters, some negatively. Other processes, such as deep rolling, were introduced only to improve the workpiece's fatigue strength. Deep rolling, however, has been developed into a widely applicable process. Modern tool technology allows us to deep roll not only rotationally symmetric parts, but also flat and free form surfaces. Moreover, it is possible to deep roll hardened components and significantly enhance their fatigue strength. Deep rolling tools consist of a roller or ball, which is pressed onto the workpiece's surface with a defined load (Figure 1). The load is high enough to cause elastic-plastic deformation in the surface zone, which smoothes the surface and induces deep compressive residual stress and cold work in the surface zone. This combination is unique to deep rolling technology.

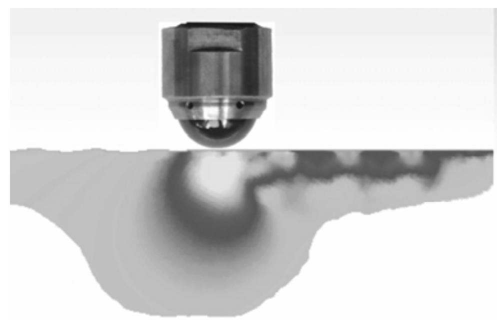


Figure 1: Deep Rolling with an HG13-tool in detail[4]

Nowadays lightweight design and increased part performance is a common industrial demand. In order to achieve this aim, it is necessary to design not only a part but also the part's properties, especially its surface zone properties. Deep rolling fulfills this objective.
A smooth surface is important not only for fatigue strength but also for its positive impact on tribological and corrosion properties. Deep rolling achieves a surface roughness even lower than Ra 0.02 µm in addition to a very good bearing ratio. The process can be incorporated into standard machine tools and applied in one setting after turning or milling.
Inducing compressive residual stress is a common method for enhancing fatigue strength. Especially in the high-cycle regime, compressive residual stress increases fatigue life. Crack growth can be reduced, in some cases even to zero, so that a failure can be prevented even if the part already has cracks.
The depth of compressive residual stress in the surface zone significantly influences fatigue strength enhancement and the reduction of crack growth. While shot peening, for example, influences only a rather thin layer of the surface zone, deep rolling induces very deep compressive residual stress. The law of Hertz explains these differing results. While the shot peening process relies on rather small grit, deep rolling tools employ a roller or ball with a larger diameter. Thus, plastic deformation and the resulting residual stress can be more deeply induced. Figure 2 shows residual stress data of high strength steel. The

residual stresses in the surface zone can be influenced by the deep rolling parameters. Increasing the rolling force increases the residual stress to a maximum of approx. 80-90% of the yield stress.
Based on empirical data and analytic calculation we are able to predict residual stress within a certain tolerance. Such process simulation and the exact prediction of the surface zone properties are research topics at several universities worldwide.

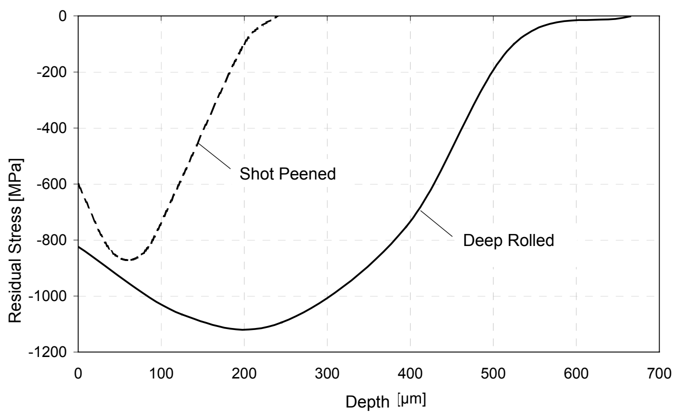


Figure 2: Residual stress for deep rolled and shot peened steel-specimen

Work-hardening the surface zone is the third effect of deep rolling that enhances a part's fatigue life. The work-hardened zone positively influences not only fatigue life, but also wear and fretting behavior. The amount of induced cold work depends mostly on the rolling force. For hardened materials, an increase of 5-10% in hardness can be obtained. For lower hardnesses, larger increases can be expected, and the hardness of some steels can be increased such that heat treatment is no longer necessary [5].

An application example easily shows the potential in life time enhancement of deep rolled parts:
Military aircraft have many highly loaded components. One example is the wheel rim. During taxiing on the runway the wheel is subjected to high loads, esp. before takeoff when the aircraft is loaded with weapons and fuel. For the design engineer it is the typical challenge of high load and lightweight design which has to solved. Applying the deep rolling process to the critical areas of this components was the solution. Figure 3 shows the application. Two fillets, which showed cracks after fatigue testing, were deep rolled. Measuring the residual stress in the near-surface zone showed that more than 1 mm of the surface zone was subjected to high compressive residual stresses. The fatigue test of the deep rolled parts proved that the application was successful. The life time was enhanced by a factor of five.
Many applications have shown that the endurance limit of steel can be enhanced by 20% and more. For cast material even increases of 140% were achieved. Still the process can be integrated easily in production and the costs are modest compared to other solutions.

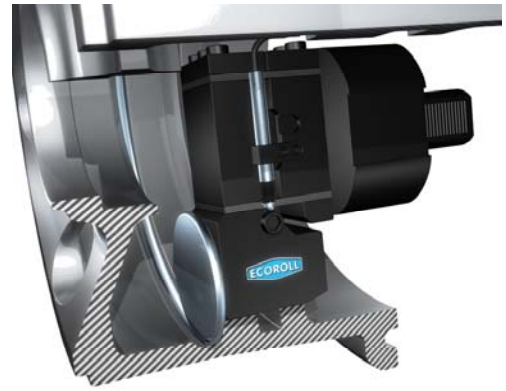
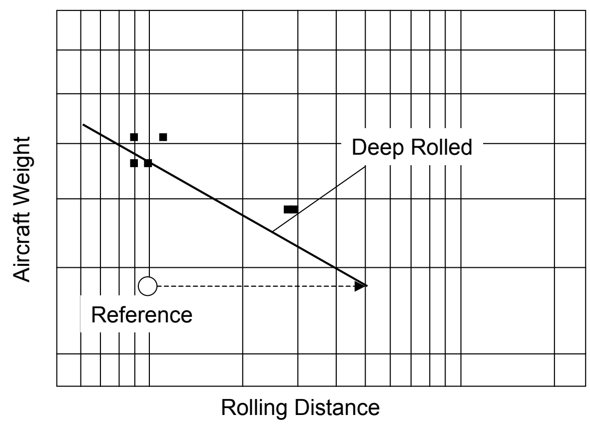


Figure 3: Deep Rolling application on aircraft wheel



⇒Service Life enhanced by factor 5

Figure 4: S/N – curve for deep rolled aircraft wheel

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