Strain Energy Release Rate in Treated Circumferentially Cracked Spring Steel

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ABSTRACT

The suspension system is a prominent piece of material that plays a vital role in the stability of a vehicle. During the service, the suspension system is subjected to different environmental conditions, at the same time it has to sustain a variety of loads. The damage of the springs is mainly attributed by its load carrying capacity under fatigue loading. Fatigue strength is the most important property for the spring steel. The energy release rate is an important parameter used to predict the life of the springs. In this experimental analysis, the authors investigate the performance of spring steel under the action of fatigue loads. The specimen preparation and the experimentations have been carried out according to the American Society for Testing of Materials (ASTM) standards. From the experiments, the strain energy release rate of the spring steels has been determined. The effects of tempering and cryogenic treatments on the performance of the spring steel have also been determined. The results have revealed that the fatigue strength and the crack growth resistance have increased with quenching and cryogenic treatments.

Keywords: Compliance, Cryogenic Treatment, Elastic Plastic Fracture Mechanics (EPFM), Strain Energy Release Rate, Stretched Zone

1. INTRODUCTION

Aggressive mass reduction trends in the automotive industry have spurred the development of suspension springs that can withstand high stresses at a reduced section size (Wise, Spice, Davidson, Heitmann, & Krauss, 2001). During the last two decades, considerable efforts have been made in the development of high-performance spring steels to meet the needs for the weight and cost savings in the automotive industry (Lee, Lee, Li, Yoo, & Nam, 1988). At present, a major application of high-quality spring steels is used in high-speed railway. Major applications of spring steel are in Railway coach axles, Crank pin on heavy machines, Crank shafts, Spline Shafts, leaf spring likewise (Cui, Liu, Pan, & Gao, 2008). Grain refining is an effective method to improve the strength and toughness of spring steels. Its microstructure varies with the reheating temperature in the course of making spring, which directly influences its final mechanical properties (Das, Dutta, & Ray, 2009; Baldissera & Delprete, 2009).

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Spring steel is the category of medium carbon steel. These steels have high hardness and can be produced by working, quenching or precipitation hardening. A study has been made to investigate the fatigue properties of high-strength spring steel in relation to the microstructural variation via different heat treatments (Wilson & Mintz, 1972; Shin, Lee, & Ryu, 1999). In order to increase the hardenability, elements such as chromium, manganese and silicon are added to these steels. Furthermore, silicon retards the conversion of the carbide to cementite during tempering. It refines the carbides and improves the sag resistance significantly (Nam, Lee, & Ban, 2000). Heat treatment creates a permanent change in the material that alters many characteristics such as fatigue strength (Ardehali Barani, Ponge, & Raabe, 2006). Spring steels are used in the quenched and tempered condition which gives optimum strength and toughness, vibrational damping (Datta, 1981). The change in microstructure and strength after the heat treatment process depends on the cooling rate obtained during quenching (Murakami, Takada, & Toriyama, 1988). Due to operational safety, springs have to meet increasing performance requirements, which concern mechanical properties, Tribological properties as well as fatigue strength (Bensely, Shyamala, Harish, Mohan Lal, Nagarajan, Krzysztof, & Rajadurai, 2009).

In the manufacturing process of mechanical springs, high tensile residual stresses are generated which reduces considerably the spring strength and service life. These unfavorable residual stresses are partially eliminated by the heat treatment (Melander & Larsson, 1993). In this process, the spring is heated uniformly below the material transformation temperature (Carneiro, Pereira, Darwish, & Motta, 2002). An experimental investigation has been conducted to assess the stress relief influence on helical spring fatigue properties (Del Llano-Vizcaya, Rubio-Gonzalez, Mesmacque, & Banderas-Hernández, 2007).

Failure of springs generally occurs due to fatigue. The fatigue process involves a competition between different crack initiating defects (Ebara, 2010; Li, Kim, & Lee, 1997). It is often a large defect situated close to the specimen surface and can generate a micro crack early in fatigue life. It is known that the fatigue loading level can have a significant influence on the location of critical defects (Li, 2008). At low loading levels internal defects can cause the majority of failures; at high loading levels defects near the surface can be more important to the fatigue process (Tanaka, Marita, & Akiniwa, 2008). The crack can initiate from the surface or at a depth below the surface depending on the materials processing conditions (Chan, 2010). During quenching, if the quenching rate is not chosen properly, quench crack/distortion may take place leading to tensile residual stress on the surface. The presence of retained austenite is undesirable. It is also found that iron sulphides present in steel along the grain boundaries facilitate the propagation of cracks generated during hardening (Ravi Kumar, Bhattacharya, Das, & Chowdhury, 2000).

When a piece of metal is fractured either by tensile or impact loading the fracture surface that is formed is rough and irregular. Its shape is affected by the metal’s microstructure as well as by ‘macrostructural’ influences (Molnarova, Mumuzi, Bacso, Fujda, Kodronova, Kuskuli, & Pokorny, 2008). Matract-A method for determining the fatigue notch-size-effect is presented based upon the development of closure in the wake of a newly formed crack growing from a notch (Park & Lee, 2000; Jones, Molent, & Pitt, 2007). In large scale yielding, in the analysis, the elastic plastic fracture mechanics (EPFM) parameter known as the cyclic $J$-integral, $\Delta J$ was adopted to observe the local plasticity at the crack tip and compared with the linear elastic fracture mechanics (LEFM) parameter known as the stress intensity factor range, $\Delta K$ (McEvily & Minakawat, 1987). Shot peening of springs is a common practice to improve fatigue strength by prestressing the surface in compression. However, excessive surface roughening during peening with coarse shot lessens the benefits of peening. The crack growth behavior depends on specimen geometry, load spectra and material type (Li, Hu, & Pan, 1990).
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