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KEY VARIABLES IN FRETTING BEHAVIOUR OF WIRE ROPE: A REVIEW

Krishan Kumar[1], Deepam Goyal[2], S.S. Banwait[3]

[1]*Department of Mechanical Engineering, NITTTR, Chandigarh, India,*
[2] *Department of Mechanical Engineering, NITTTR, Chandigarh, India,*
[3]*Department of Mechanical Engineering, NITTTR, Chandigarh, India,*

Abstract*— Wire ropes are used in elevators, cranes, mine hoisting, bridges, aerial ropaways system and several other applications involving safety of human life. Consequently, an efficient and safe performance of wire rope has always been an area of research. Fretting behaviour under repeated cyclic load in practical application plays a crucial role in performance of wire rope. Fretting behaviour is affected by a number of variables viz. material, strength, lubrication and coating and environmental factors like corrosive medium, operating temperature etc. There is a huge potential for further research in the area of fretting behaviour analysis. This paper presents a state- of- the- art review of key variables, their effect as well as remedial solution of fretting behaviour of wire rope.

Keywords*— Wire rope, material, fretting fatigue, lubrication, coating, sheave, steel, polymer

INTRODUCTION

Wire ropes have been in use since 13th century **[1]**. Wire ropes have three basic components *viz.* wire that forms strands, a core, and multi-wire strands that are helically wrapped around the core as shown in figure 1 **[2].**

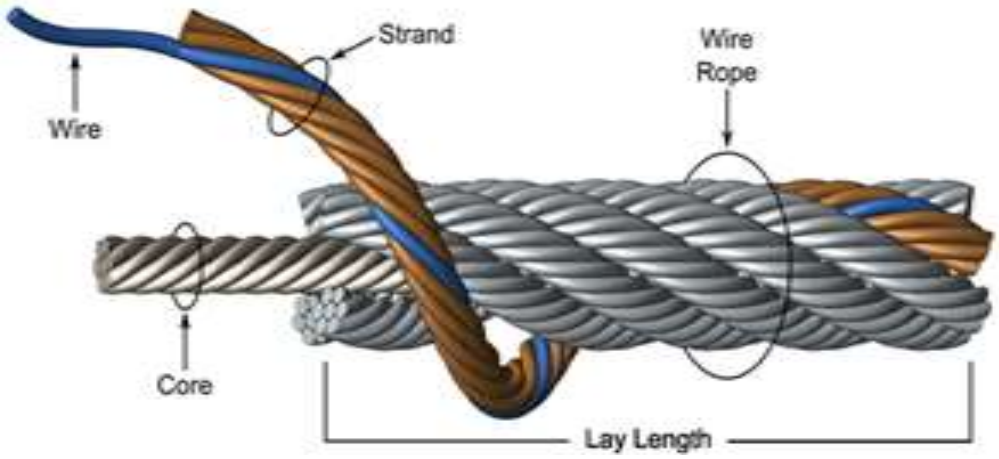

Figure 1 Various components of wire rope

Due to helical structure of wires in wire rope, a radial contact pressure is generated between wires **[3].** Cyclic or fatigue load results from repeated operation **[4, 5]**.

I. MATERIALS FOR WIRE ROPE

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it. To meet the basic requirements of wire rope, various materials are used. Materials of wire ropes are broadly divided in two segments *i.e.* metallic wire ropes and non- metallic wire ropes.

A. Metallic Wire Rope

Metallic wire ropes are mostly used for high strength applications. For high strength steel wire mass percentage of carbon varies from 0.4 % to 0.95 %. Various common constituents of carbon steel by mass percentage are tabulated in Table 1. Wire ropes used in corrosive environment are made of Stainless Steel **[7].**

Table 1 : Composition of plain carbon steel by mass percentage for wire rope

Constituent	Percentage composition
Silicon (Si)	0.1 – 0.3
Manganese (Mn)	0.5- 0.8
Phosphorus (P)	<0.035
Sulphur (S)	<0.035
Chromium (Cr)	< 0.15
Nickel (Ni)	< 0.20
Molybdenum (Mo)	< 0.05
Copper (Cu)	< 0.25
Aluminium (Al)	< 0.01

B. Non-metallic Wire Ropes

Wire rope made of nylon and polyester fibers has the advantage of high strength to weight ratio **[8]**. Under corrosive environment, wire rope made of synthetic plastic material **[9]**.

II. MECHANICAL PROPERTIES OF WIRE ROPE

Wire rope is required to have high tensile strength, high stiffness and flexibility in bending. **[10]**.Loss of material from wire rope causes reduction in strength **[11]**. Strength of wire rope depends on percentage of carbon **[12]**. The increase in the tensile strength cause reduced ductility **[13]**. Strength of wire rope can also be improved by compaction, stress relieving **[14]**.

III. FRETTING BEHAVIOUR OF WIRE ROPE

During application, wire ropes are subjected to cyclic stretching or elongation, mechanical vibration and bending loads. Cyclic load and fretting wear causes initiation, propagation and consequently, the fracture of wire rope **[15]**. Hard surface have better fatigue resistance **[16]**.Wear behaviour of the wire is affected by contact pressure, environmental condition **[17]**. Fretting increases with increase in cross-angle **[18].** Deterioration of rope is also caused by bird-caging effect **[19]**. Fretting behaviour of material is also a function of its grain size **[20]**. Fretting fatigue depends on normal contact load, bulk cyclic stress and relative slip **[21]**. Fretting largely depends on co-efficient of friction **[22]**. Shot peening with any of coating improves fretting resistance **[23]**. Co-efficient of friction depends on contact pressure **[24]**.
Fretting can analysed by optical and scanning electron microscopy **[25]**. Residual stresses improve fretting resistance **[26]**. MAO and HA coating improves fatigue behaviour of material **[27]**.Wear debris in combination with vibration speed up the wear process **[28]**. Hardness of surfaces have marginal effect on fretting fatigue **[29]**. Reduction in sheave diameter results in a higher wear rate (μm^3/cycle) **[30].** Torsional fretting in wire ropes depends on normal contact force, angular displacement amplitude, and number of cycles **[31].** In wire ropes, tangential force and relative slip increases with increase in strain amplitude **[32].** Various kinematic factors plays a strong role in fretting behaviour of wire rope **[33]**. Wear co-efficient of steel wire decreases with increase in pH value of corrosive medium **[34]**. For hoisting wire rope fretting is a function of terminal mass **[35]**.
Under axial tensile load, effect of torsional shear stress in wire rope can be neglected **[36]**. When a wire rope coated with solid lubricant wear resistant improves **[37]**. In acidic medium, the relative slip between wires increases and co-efficient of friction between wires decreases **[38]**. Broken wires in wire ropes can be detected by using acoustic emission **[39]**. Effects of corrosive medium are similar to that of acidic medium **[40]**. Nylon pulley improves fatigue life of wire rope **[41]**. Fretting fatigue behaviour of wire rope also gets affected by strain ratio **[42]**. A wire rope made of coated wires with coating of bonded MoS_2 had excellent fretting resistance **[43]**. For wire rope made of Inconel 690 failure is caused by oxidation, deformation, fatigue **[44]**. Co-efficient of friction of Polymer shows function of relative sliding motion **[45]**. Fretting behaviour of wire mainly depends on friction, crack initiation and propagation **[46].** Wire ropes generally fail due to fretting fatigue **[47]**. Various failure mode of wire rope are fracture i.e. low stress brittle fracture, wear and corrosion **[48]**. Torsion angle also affect fretting fatigue behaviour of steel wire **[49]**.
Fatigue life of steel wires has also been affected by crossing angle **[50]**. During application, a wire rope can be subjected to combined longitudinal and torsional fretting **[51]**. FEM has been used to get contact stress and relative slip **[52]**. Under dry condition, co-efficient of friction between wires nears 0.73. Under lubrication condition, co-efficient of friction nears 0.35 **[53]**. Wear scar affect mechanical properties of wire **[54]**.

A. Effects of fretting on performance of wire rope

Fretting results in wear and consequently material loss from wire surface due to inter-wire friction. Load carrying capacity of wire rope gets reduced.

B. Remedies for wire rope fretting

There have been a number of ways to reduce fretting of wire ropes. There have been two types of lubricants that are used in wire ropes viz. penetrating and coating **[55]**.
Lubrication promotes unrestricted movement of the wires in the rope **[56]**. Conduits for injecting the lubricant may be used **[57]**.Lubrication will also prevent or reduce corrosion **[58]**. Thermoplastics and thermoset fibers have been added to

the ropes **[59]**.For applications under high fretting, it needs a hard coating layer **[60]**. Plastic fibre at core provides good lubrication **[61].**

V. CONCLUSIONS

Fretting behaviour of wire rope depends on a number of variables and most prominent variables are briefly described from the review of work done by various researchers on wire ropes as follows:

(i) Lubrication of wire rope with grease and graphite increases service life by 40%.
(ii) Most suitable parameter to characterize the wear behaviour are scar depth and volumetric loss of material in wear.
(iii) Coating of various materials like graphite, Poly tetra fluro ethylene, Molybdenum Disulfide, Diamond like Carbon, hard Chromium & sprayed Tungestan Carbide-Cobalt coating improves fretting behaviour of steel wire ropes.
(iv) Fretting fatigue depends on environmental factor.
(v) Fretting can be analysed using a number of method or test rig viz. scanning electron microscope (SEM), X-ray diffraction.

Table 3: Performance Assessment of key variable in fretting behaviour of wire

Sr. No.	Variable		Findings	References
1	Material: Fibre of Nylon, polyster, poly-propelene as wire rope material		Polymer gives high strength to weight ratio	Foster,2002**[8]**
2	Strength of Steel wire rope		Strength reduces with abrasive wear	De Silva & Fong, 2001 **[11],** Shiota*et al*., 2005 **[12],** Mahmoud, 2007 **[13]**
3	Effect of variables on Fretting Fatigue behaviour of wire rope			
	i.	Dynamic wear & crack propagation	Fretting fatigue decrease with increased wear & crack	Wang et al.,2016 [15]
	ii.	Fretting	Reduce fatigue strength	Allen et al., 2003 [16]
	iii.	Contact pressure, lubrication & relative humidity	Reduced contact pressure, increased lubrication & relative humidity reduces wear	Urchegui, 2008 [17], Xu et al., 2006[37]
	iv.	Crossing Angle	18° crossing angle gives maximum contact area	Zhang et al., 2018 [50]
	v.	Grain size	Coarse grain gives better fatigue life	Jayaprakash, 2014 [20]
	vi.	Diamond like coating (DLC), Shot peening, hard chromium & WC-Co, MoS2, Coating	Improved fatigue Life	Kalin &Vizitin, 2006 [22], Kubiak et al., 2005[23]
	vii.	Corrosive media & Pure water as operating media	Increased pH results in increased anti-wear properties, Oxidation & delamination, consequently reduced fretting life	Wang et al.,2013, [34], Xu et al., 2013[38]
	viii.	Torsion Angle	Increased torsion angle results in reduced fretting life	Wang et al., 2017 [49]

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