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RESEARCH

Mild Steel Tribology for Circular Economy of Textile Industries

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ABSTRACT

Circular economy is still an imaginary field. In this manuscript, mild steel material is used to evaluate the coefficient of friction (COF) of cotton fabric. COF is evaluated to facilitate circular economy of textile industries. Scanning electron microscope (SEM), optical profilometer, mechanical profilometer and tribometer were used for AISI 52100 steel balls and cotton textile waste. The fabric surface was found distorted and damaged due to joggling, bobs, jerks, and pills surface defects. These defects produced due to physical and chemical treatments. The average coating surface roughness parameters were Rmax (0.35 µm), Rz (0.50 µm), and Rp (0.45). The dynamic coefficient of friction (COF) values was found 0.21 to 0.12 in warp and 0.17 to 0.10 in weft directions. The tensile strength and hardness values of mild steel 2600 MPa and 65 on HRC, respectively proved that metallic surface is smooth and soft. The smaller COF values and soft metallic surface produced low grip and cutting resistance due to damaged and distorted textile wastes. Based on COF values, deformation, wear and morphology evaluations, the mild steel machinery parts could be used operationally for recycling of textile wastes. for surface alterations of textile machinery parts. Furthermore, damaged, and distorted post-consumer textile wastes required hard, high strength and well finished machinery parts surfaces for its recycling.

1. INTRODUCTION

Circular economy is an emerging system of recycling and manufacturing with minimum wastes. It has appeared as a modern solution for textile industries. Various metallic coatings and materials have been used to increase tribological properties of textile machinery parts [1-3].

Fatigue, corrosion and abrasiveness produced practical problems in textile manufacturing and recycling industries [4,5]. Cutting, shredding, recycling, spinning, weaving, and finishing are prime recycling and manufacturing processes [6]. These processes are mirror image of quality and performance of recycling and manufacturing products [7]. The machinery components, parts and tools are made up of mild steel materials. Moreover, these machinery parts should have prime fatigue, wear, corrosion resistance and abrasive resistance to overcome the functional problems [8,9]. These functional problems required innovation and research development for industrial practices [10-12].

Industrial tribology is an emerging field. Generally, coating materials like oxides, carbides, carbon based, nitrides, diamond-like coatings (DLCs) and multipurpose coatings are utilized for enhancement of tribological properties [13-15]. In manufacturing and recycling industries, the machinery components usually consist of two parts metal matrix and surface coatings. Metal matrix used for component design and to withstand (toughness, yield strength and tensile strength) during manufacturing and recycling processing. Similarly, surface coatings are used for surface modification. Tribological studies of metal matrix and surface coatings enhanced quality and performance of recycled and manufactured textile products [16-22].

The study of friction and wear of interacting surfaces is termed as tribology. Fundamentally, two techniques are used to measure wear and friction. In first technique, a body of mass “m” slides linearly over cotton fabric as a counter object. This technique is implemented to observe static and dynamic coefficient of friction (COF). Mathematically, the dynamic COF is given as follows.

$$\mu_{dynamic} = \frac{F}{mg} \quad (1)$$

where “F” is normal force, “$\mu_{dynamic}$” is friction constant, “g” is gravitational acceleration constant, and “m” is mass of sliding body.

In second technique, inclined surface is practised to observe the static COF. The new formulation is described below.

$$\mu_{static} = \tan\theta \quad (2)$$

where “μ_{static}” is static friction constant and “θ” is inclined angle between sliding body and surface [23-25].

The current research deals with tribological properties evaluations of mild steel and cotton fabrics for industrial applications. In this manuscript, AISI 52100 mild steel metallic matrix material balls are used for wear and COF evaluation against post-consumer cotton fabric. A new tribometry technique was matured. The sliding and reciprocating principles were used for wear evaluation and optimization, respectively. The COF values were measured using normal force, speed, time and sliding distance variations. CETR/Bruker UMT-2 tribometer was used for tribology testing. The force, speed, time and sliding distance were varied 0.5 to 9 N, 1 to 10 mm/sec and 0 to 80 m, respectively. Scanning electron microscope (SEM) is used for cotton fabric and steel ball surface analysis. Optical and mechanical profilometers were exercised for cotton fabric and steel ball surface roughness evaluations. The surface hardness of ball surface was also observed using Rockwell hardness tester.

2. MATERIALS AND EXPERIMENTAL TECHNIQIES

2.1 Materials

C2 (fabric code) dark green pure plain-woven cotton fabric was used for experimentation. The fabric weight was 267 grams per square meter (GSM). The linear and thread densities were 29 X 29 tax and 18 X 36 threads/cm in warp and weft directions, respectively. Besides this, the thread diameter and thickness were 0.345 mm and 0.45 mm, respectively.This is known as subjective assessment [26].

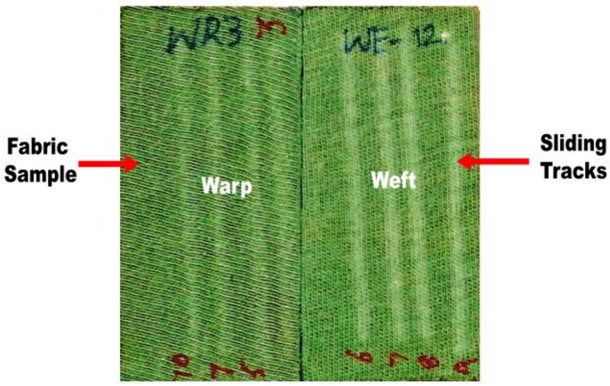


Fig. 1. Cotton fabric samples.

Ten steel blocks of 25 x 10 x 50 mm dimensions were prepared. The fabric cotton strips of same dimensions were pasted on steel blocks with epoxy glue. The twenty seconds curing time was adopted to avoid the penetration of glue into cotton fabric.

AISI 52100 steel balls were used to observe tribological properties of post-consumer cotton textile. The typical chemical composition was shown in Table 1.

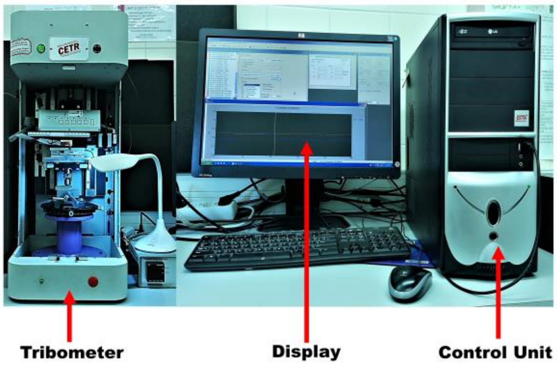
Table 1. AISI 52100 steel balls chemical composition.

Element	Chemical composition [%]					
	%C	%Si	%Mn	%Cr	%Ni	%Cu
AISI 52100 steel ball	0.95	0.30	0.40	1.70	0.30	0.25

The density and young modulus were 7.8 g/cm^3 and 200 GPa. The tensile strength and hardness were 2600 MPa and 65 on HRC scale. The metallic balls of 10 mm diameter were used for wear and COF evaluations.

2.2 Tribometer method description

The COF was observed using CETR/Bruker UMT-2 tribometer. The experimental setup was shown in Fig. 2 (a). The tribometer consists of two parts ball slider and sample holder, see Fig. 2 (b).



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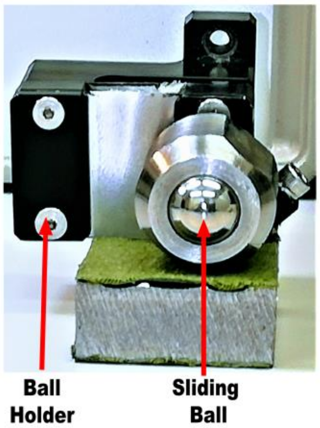


(c)

Fig. 2. (a) CETR/Bruker UMT-2 tribometer (b) experimental setup (c) ball slider.

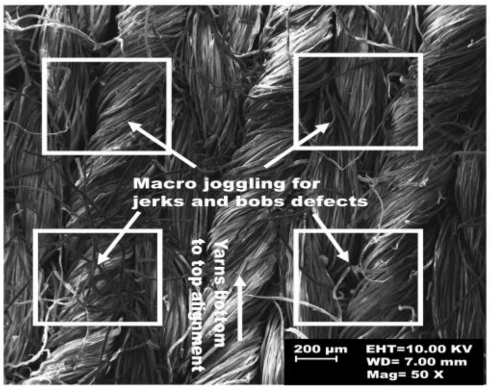
The slider (Fig.2 (c)) has 0-200N force and 0.5-15mm/sec speed range. The sample holder used to fix samples horizontally. It also avoids the wrinkling of cotton fabrics.

The wear and coefficient of friction (COF) of cotton fabrics were observed in warp and weft directions. The normal force, speed, time and sliding distance 0.5 to 9 N, 1 to 10 mm/sec, 4 to 40 sec and 0 to 80 m, respectively to evaluate tribological properties.

3. REUSLTS AND DISCUSSIONS

Initially, SEM is used for surface characterization. The post-consumer cotton fabric surface was studied in warp and weft direction. The newly manufactured cotton fabric passed through various physical and chemical treatments during service life. The treatments produced various defects and internal stresses on cotton fabric surface [27]. At lower magnification, the SEM images of warp and weft direction were shown in Figs. 3 (a) and 3 (b), respectively. The yarns weaved from left to right and bottom to top for weft and warp directions formations, respectively.

The cotton fabric surface was also study at higher magnification using SEM. The macro joggling also produced due to physical and chemical treatments. The joggling creates surface hairiness, loss of yarns and pills. These effects damaged and distorted the fabric surface. The damage and distortion produced tangling effect on fabric surface [28]. The details are depicted in Figs. 4 (a) and 4 (b).



(a)

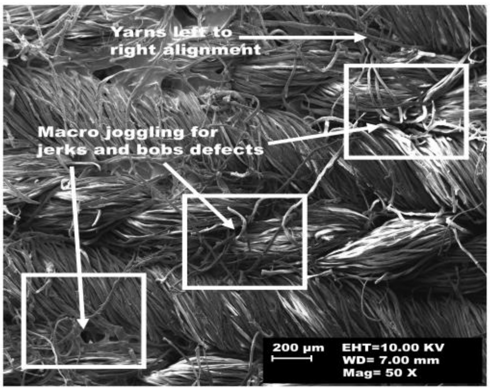


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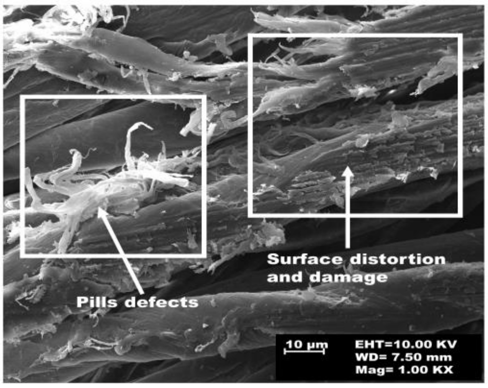
Fig. 3. (a) Warp direction SEM image (b) Weft direction SEM image.



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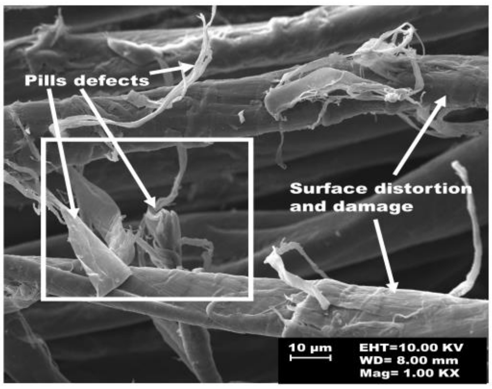
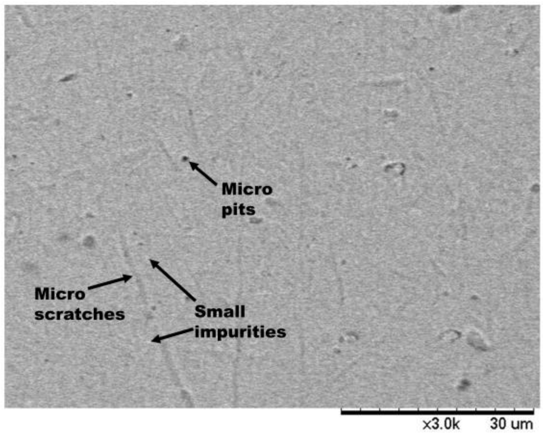


(b)

Fig. 4. (a) Warp direction SEM image at higher magnification and (b) Weft direction SEM image at higher magnification.

The deformation and wear of cotton fabric depend on interaction between sliding body and fabric. The tribology was studied using sliding and reciprocation motions.

The steel balls surface is also observed using SEM. Some impurities are detected at lower and higher magnifications, see Figs. 5 (a) and 5 (b). The surface was found smooth. The surface smoothness was also confirmed using optical and mechanical profilometers [29]. The surface roughness was measured and shown in Table 2. The surface roughness parameters Ra, Rz and Rp refer to average profile value, average peak to peak value and maximum peak value, respectively. However, some impurities, micro scratches and micro pits are also detected, see Figs. 5 (a) and 5 (b).



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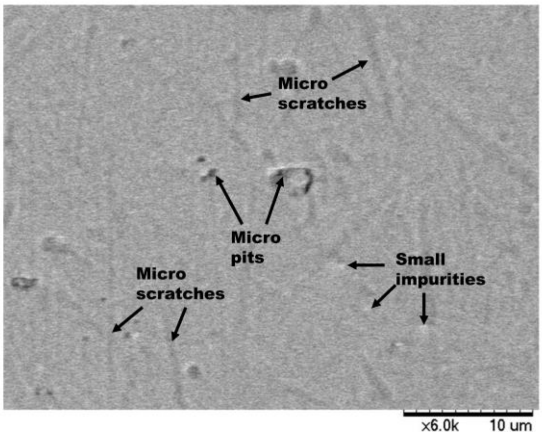


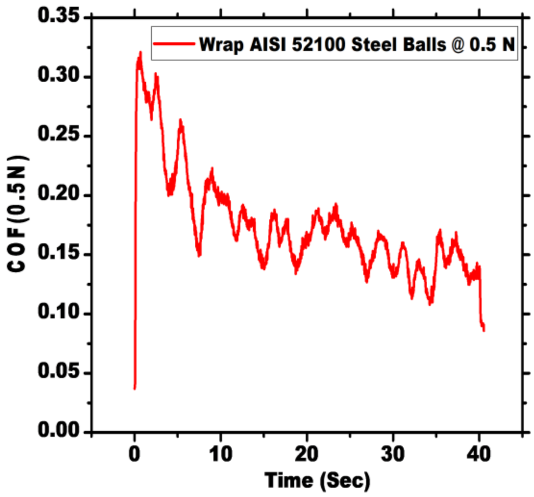
(b)

Fig. 5. (a) AISI 52100 steel balls SEM image at (X 3,00 K) and (b) (X 5.00 K) magnifications.

Table 2. AISI 52100 steel balls surface roughness.

Device	Surface roughness parameters		
	Ra	Rz	Rp
Optical	0.34	0.67	0.56
Mechanical	0.24	0.25	0.13

The representative graphs of post-consumer cotton fabric were shown in Figs. 6 (a) and 6 (b). The graphs are manifested in warp and weft directions. The force, speed and time have been varied to observe COF.



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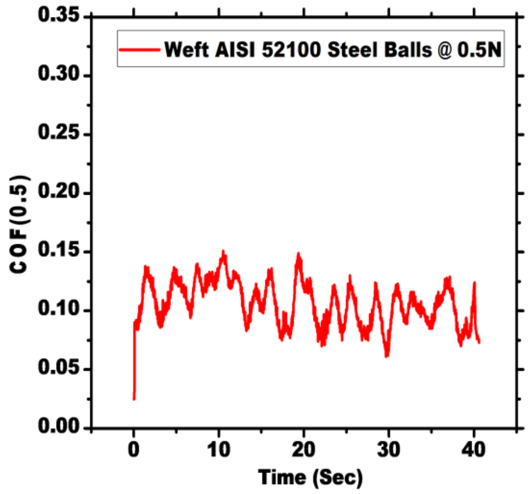


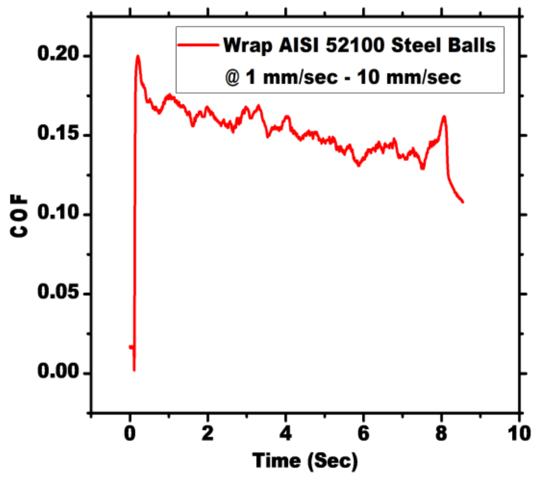
(b)

Fig. 6. (a) AISI 52100 steel balls COF in warp direction and (b) COF in weft direction.

The Figs. 7 (a) and 7 (b) show the typical graphs of COF for speed variations. Moreover, graphs 7 (c) and 7 (d) show the response of fabric COF for speed and force variations. The observations express that at constant speed of 1 mm/sec, in case of AISI 52100 steel balls, for value of force increasing from 0.5 to 9 N, the COF value decreases from 0.21 to 0.12 in the warp and 0.17 to 0.10 in weft directions, see Fig. 7(c). Moreover, at constant force of 8 N, in case of AISI 52100 steel balls, for the value of speed increasing from 1 mm/sec to 10 mm/sec, the post-consumer fabric COF value increases from 0.12 to 0.15 in warp and 0.11 to 0.14 in weft directions, see Fig. 7 (d).

Several observations can be predictable using COF Evaluations. The COF results were found slightly higher in warp direction. The fabric structure, pattern, weight, and twist value contribute to these effects [30-33].

Typically, this type of behaviour is not found for other textile materials. Moreover, the nature of counter body and fabric materials also contributes [23,33]. The parallel (weft direction) threads arranged from left to right serve as reference track. The tangling, damage, piles and distortion of cotton fabric present more encounters to wear and deformation [28]. The production of elastic and plastic deformation on cotton fabric is necessary for initial cotton wear and erosion. The wear and erosion of cotton fabric starts with local removal of polymer material from surface. For value of force and speed 0.5 to 9 N and 1 to 10 mm/sec, regarding sliding, no wear, erosion, deformation, and local removal of materials are found. The SEM images were found same as shown in Figs. 3 (a), 3 (b) and 4 (a), 4 (d). Furthermore, the tracks of weft and warp directions are shown in Fig.1.



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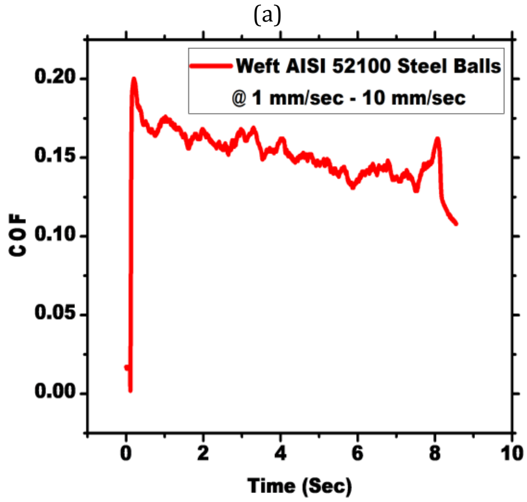

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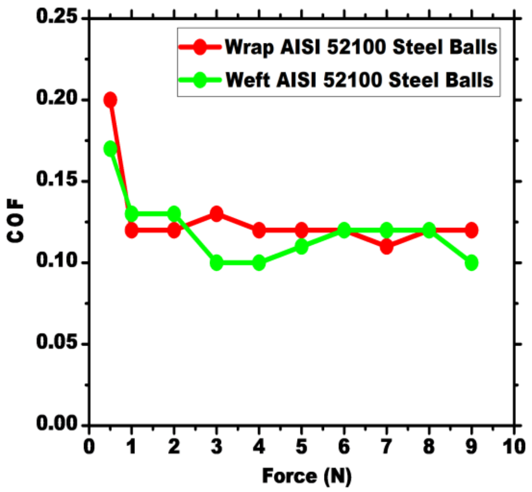

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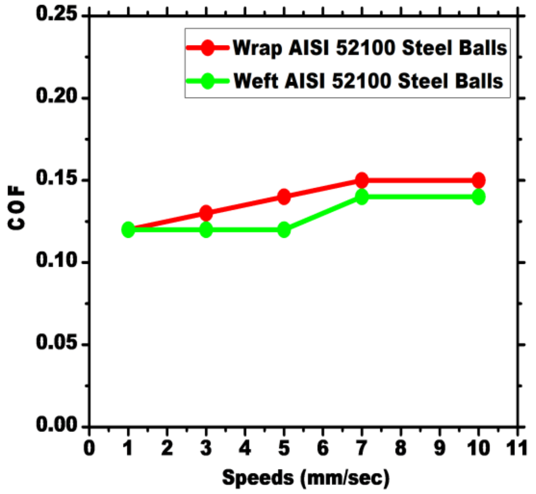
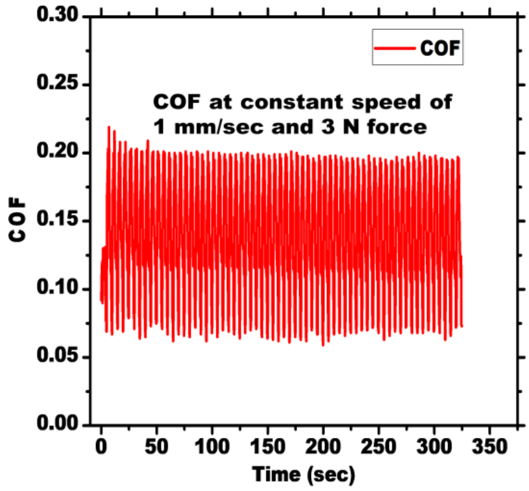
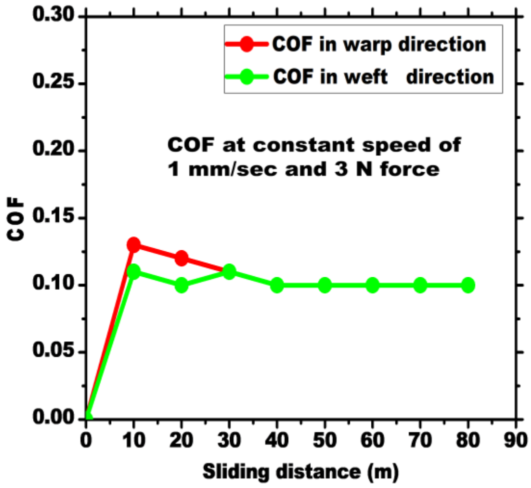


(d)

Fig. 7. (a) Typical COF graph in warp direction, (b) typical COF graph in weft direction, (c) COF for force variations and (d) COF for speed variations.



(a)



(b)

Fig. 8. (a) COF versus time variations of reciprocation (b) COF versus sliding distance observations.

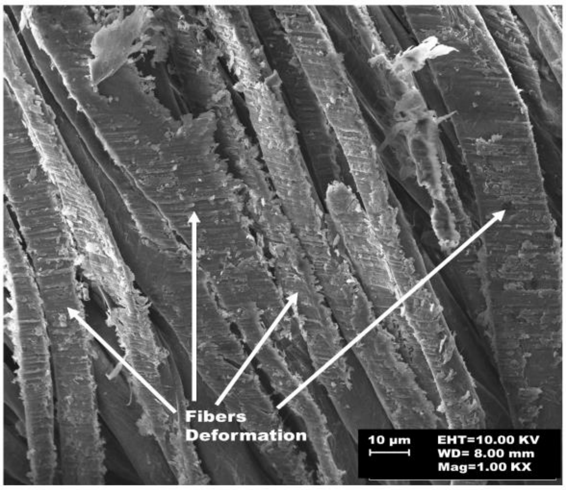
The sliding motion is changed to reciprocation motion. The distance is increased to observe COF, wear and deformation creation. At a load of 3 N and 1 mm/sec speed, for 80m of sliding distance, AISI 52100 steel balls deformed cotton fabric surface. There is no wear detection in this phenomenon. It is shown in Figs. 8 (a) and 8 (b). Formally, there is a little variation of COF value in weft and warp directions. The COF value observed constant for both directions just after 25 m of sliding distance. The creation of small deformation on cotton surface is sign of grip between cotton fabric and metallic surface. Higher the creation of plastic deformation, better will be the grip. Lower the grip higher will be the cutting resistance [34].

The corresponding SEM images of deformed cotton fibres are shown in Figs. 9 (a) and 9 (b).

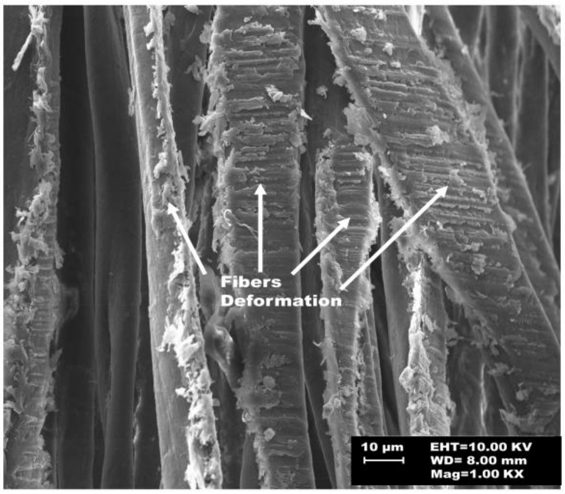
The COF results are of great importance for textile industries. Kothari et al. observed the behaviour of textile fabrics and textile machinery parts components. The group proved that the behaviour could be expressed in terms of grip and cutting resistance index (CRI) [34-36].

Textile machinery parts are mostly made up of mild steel matrix materials. These matrix materials show high cutting resistance and lower grip between machinery parts. This is due to lower COF values.

The damaged and distorted post-consumer cotton along with three-dimensional drift fibers exhibit small grip and higher cutting resistance during recycling. It decreases the quality and performance of recycled products [37,38]. The evaluations show that the sliding can only produce small deformation on fabric surface, see Figs. 9 (a) and 9 (b).



(a)



(b)

Fig. 9. (a) SEM image of weft deformed fibers (b) SEM image of warp deformed Fibers.

The small deformation is a representation of poor grip between fabric and metallic machinery parts. Collectively, poor grip and lower COF values between textile wastes cause the tangling and buckling of machinery parts. According to subjective assessment, higher the values of thread setting density, linear density, weight per square meter (GSM) and tensile properties better will be the performance and quality of textile products [39-42]. Therefore, these textile wastes required higher COF for better grip and lower CRI. Generally, COF values less than 0.20 may be observed suitable for newly manufactured textile products to avoid surface damage and distortion. The virgin materials may also include in these categories. But COF values greater than 0.25 may be find out better for textiles wastes types. The results proved that surface modification is required to enhance the quality and performance of textile recycled products.

4. CONCLUSION

AISI 521OO steel balls have been used to study COF, wear and deformation between counter body and post-consumer cotton waste. The surface characterization of steel balls and post-consumer cotton waste have been determined for quality and performance investigations.

At lower magnification, the cotton fibres were found round. The defects like jerks, bobs and joggling were also observed. These defects caused cotton fabric surface damage and distortion due to physical and chemical treatments. The steel ball surface has been found smooth. The tensile strength and hardness were 2600 MPa and 65 on HRC scale, respectively.

The COF values were found 0.12 to 0.21 in the warp and 0.10 to 0.17 in weft directions. The COF results were found slightly higher in warp direction. The change of force and speed have no influence on post-consumer cotton fabric surface. But increase in sliding distance produced plastic deformation on cotton fabric surface.

The lower COF value, hardness and mechanical strength were produced small grip and higher cutting resistance index. The evaluations proved that the rough, damaged, and distorted post-consumer textile wastes required hard, high strength and well finished surfaces machinery parts for its recycling.

Acknowledgement

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