Investigation of the Tearing Performance of Fabrics with Various Constructions, Woven from Different Yarn Spinning Systems

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***Abstract*— Tearing resistance of worsted fabrics as the main type of materials used in the garment industry is the purpose of this study. To this end, the tearing performance of worsted fabrics with various weave structures and weft yarns with different yarn spinning systems, after the finishing process and in the grey state has been investigated. The total tearing energy (TE) as a tearing resistance index was used for the analysis and comparison of the results. According to the outcomes, weave structures with the lower construction firmness (CFF factor) had the higher tearing energy. In addition, two-ply ring yarns had the highest tearing energy among the studied yarns; while the solo yarns tearing energy was higher than siro yarns, and the single ring yarns had the lowest tearing energy. Moreover, the finishing process negatively affected the tearing energy of worsted fabrics.**

***Keywords:* fabric structure, tearing behaviour, worsted fabric, yarn spinning system**

I. Introduction

Tearing behaviour is one of the important properties of woven fabrics in various end uses such as outdoor clothing, uniforms and especially industrial fabrics that are exposed to rough handling in the use and also in cases, where the propagation of tear would be catastrophic. Due to the importance of tearing performance of fabrics, measurement and analysis of the tearing behaviour of fabrics has been the subject of many previous research works. The tear resistance of fabrics is a property, which determines the material strength under both static force (a static tear test) and kinetic force (a dynamic tear test). The fabric property that is usually measured in this case, is the force required to propagate an existing tear.

Teixeira *et al.* (1955) studied the effect of fabric weave pattern and texture, yarn twist and yarn structure on the tearing behaviour of acetate woven fabrics through a tongue-tear test. It was concluded that the factors of fabric which affects the tearing behaviour can be listed as the reciprocal force required to pull the yarn out of the fabric, the crimp level and crimp balance, the yarn spacing and cover factor in the fabric, the deformability of the fabric in its own plane and the load-elongation curve of the conditioned yarn [1]. By measuring the tearing strength of textile fabrics using the tongue and trapezoid methods, Turle (1956) concluded that the results of two types of testing differ significantly [2]. Abbott *et al.* (1971) studied the effect of the PVC plastisol coating on the woven fabric tearing property. Plain weaves lost about 25% of their tearing strength on the average, twills about 60% and baskets at least 70%. Regardless of this, the basket weaves had the highest tearing strengths in the coated state [3]. Hamkins and his co-worker (1980) investigated the presence of yarn slippage and local yarn extensions, both across and along the tear. Analysis of the results revealed that during the trapezoid tear test, for a low mobility fabric, the transfer of load from yarns near the edge can lead to high stress concentrations [4]. Scelzo *et al.* (1994) reported that the tearing procedure can be summarized in three steps, including resistance to pull-in, resistance to jamming and resistance to yarn breakage. An attempt was also made to develop a spring model for the tongue tearing method [5,6]. In the research by Witkowska *et al.* (2008), the problem of tear strength was analysed, and appropriate measurements and the correlation between the results achieved from different tear methods for a group of protective textiles were carried out. It was found difficult to find a correlation between static tearing test methods due to the different direction of force application and dissimilar method of calculating the tearing force [7]. Mukhopadhyay *et al.* (2006) concluded that the ring spun yarn fabric shows the higher tearing strength compared with the rotor spun yarn fabric. In addition, the tearing strength along the bias direction is between the warp and weft wise tearing strength [8]. In another study, Dhamija *et al.* (2007) observed that the fabric made from compact spun yarn was more tear resistant due to the yarn's smoothness, which provides the greater movement freedom for yarns and higher load to carry. Similarly, weave structures with more floating yarns, because of easier yarn movement and the ability of yarns to group with each other, show higher tear strength [9]. Teli *et al.* (2008) evaluated the strength properties of the fabric with respect to tensile, tear and bursting strength concerning the weft yarn structure, yarn count, twist and weft density using regression equations. The results show that the fabric with ring weft yarns had the higher tear strength compared to the fabric with rotor weft yarns [10]. In research done by Witkowska and his co-workers (2008), analysis of the stages of static tearing in cotton fabrics for wing-shaped test specimens was carried out. The successive tearing stages, the parameters of tearing zone, such as the length and depth, and the number of threads occurring in this zone, tearing parameters, such as the tear force increment and elongation increment during the tearing process were investigated [11]. Almetwally *et al.* (2010) revealed that the difference between the two compact and ring spun yarns is reflected in the properties of fabrics woven from

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both. Statistical analysis showed that there is no significant difference between both types of fabrics regarding the tear strength and abrasion resistance. But in relation to the tensile strength, air permeability and stiffness, compact fabrics were superior to ring fabrics [12]. Wang *et al.* (2011) carried out finite element modelling of woven fabric tearing damage. Tongue-tearing behaviours of two plain and two twill-woven fabrics were tested to obtain the tearing load–displacement curves and tearing damage photographs. The factors that influence the tearing strength, such as the friction among warp and weft yarns, weaving structure, and weaving density, were also discussed [13]. Triki *et al.* (2011) developed a criterion for the tearing energy of woven fabric, which is computed as the variation of tearing work as a function of tear crack surface area. This tearing criterion can be used in order to study the effect of fabric structure on its tearing performance [14]. Bilisik *et al.* (2011) examined the tearing strength of the dry and wet states of rubbed flocked fabric and washed flocked fabrics. Their results showed that the tearing strength of substrate was the highest; however, the washed flocked fabric had the lowest tearing strength [15]. In the research work by Wang *et al.* (2013) the trapezoid tearing behaviours of uncoated and coated woven fabrics in experimental and finite element analysis approaches were studied. The tearing strength and damage morphologies of the two kinds of fabrics were compared to find the tearing damage differences between uncoated and coated woven fabrics during the trapezoid tearing process [16]. Wang *et al.* (2013) proposed the analytical modelling on mechanical responses and damage morphology of flexible woven composites under the trapezoid tearing. From the model it was found that the failure strain and the elastic modulus of the yarn as well as the weaving density of the fabric are the key factors affecting the tearing strength of flexible woven composites [17].

Previous studies on the tearing behaviour of fabrics can be summarized as:

- the analysis of the existing tear resistance models and their possible application
- analysis of static tear resistance methods
- finding the significant common features and differences in the behaviour of samples, which underwent different tearing methods
- the characteristics of particular tearing methods dependent on the sample shape and tearing direction in relation to the tearing force
- finding the relationship between the results obtained by different tearing methods, and the influence of calculation method results on the mean tearing force

Considering the results obtained from other research works, it was concluded that there is still a need to investigate the effect of fabric structural parameters such as the weave pattern and the characteristics of the yarns woven in the fabric, on the tearing behaviour of woven fabrics. Moreover, it is essential to propose a single, comprehensive and precise parameter for quantifying the tearing performance of the fabrics along the total tear path.

In this regard, in the current study, the tearing performance of worsted fabrics with various weave structures and weft yarns with different yarn spinning systems, in the grey state and after the finishing process has been probed.

II. EXPERIMENTAL

A. Materials

In this study the effect of weft yarns quality, which are produced in different yarn spinning systems, fabric weave structure and finishing process of worsted woven fabrics on the static tearing performance of worsted fabrics were investigated. A two-plied ring yarn of the metric number 26 Nm (45/55wool-polyester) was used for warp yarns. Weft yarns were 45/55 wool-polyester of the metric number 26 Nm, which were produced in various spinning systems, including Solo, Siro and Ring (single and

TABLE I
FABRIC SPECIFICATIONS

weave structure	fabric code	weft yarn type	weight (g m^{-2})	warp density (per cm)	weft density (per cm)	thickness (mm)
plain	pr1	r1	195.09	30	25	0.34
	pr2	r2	194.34	30	25	0.34
	psi	siro	193.47	30	25	0.33
	pso	solo	193.22	30	25	0.35
hopsack2/2	hr1	r1	203.82	30	25	0.43
	hr2	r2	202.54	30	25	0.43
	hsi	siro	203.58	30	25	0.43
	hso	solo	202.65	30	25	0.43
twill2/1	t1r1	r1	195.56	30	25	0.41
	t1r2	r2	193.65	30	25	0.41
	t1si	siro	193.95	30	25	0.40
	t1so	solo	193.12	30	25	0.40
twill2/2	t2r1	r1	204.27	30	25	0.43
	t2r2	r2	202.32	30	25	0.43
	t2si	siro	202.29	30	25	0.43
	t2so	solo	202.51	30	25	0.43

two-plied ring yarns in this paper will be called R1 and R2, respectively). Fabrics were woven in four different weave structures as follow: Plain, Hopsack 2/2, Twill 2/1 and Twill 2/2. Tearing properties of fabrics were assessed both in grey and finished states. The fabrics were finished according to industrial finishing process of worsted fabrics. The fabric characteristics are presented in Table I.

B. Testing Procedure and Data Acquisition

In order to study the tear behaviour of fabrics, these fabrics were tested in the weft direction through a modification of the ballistic tear test method (BS 4253), by an Instron (5566) tensile testing machine. In this case, the tearing path was parallel to the warp yarns; hence the weft yarns were ruptured through the tearing test. To this end, five samples from each group of fabrics were cut in the warp direction and their dimensions were 5×10 cm^2 (warp-wise length was 5 cm). In a distance of 3 cm from the sample edge, a line was drawn in the warp direction. Then a perpendicular line was drawn in the middle of the previous line, which was cut (Fig. 1). Then the two cut ends of the samples were placed in the upper and lower clamps of the tensile testing machine. The gauge length was 1.5 cm. The upper jaw moved with a speed of 300 mm min^{-1} until the sample was torn, completely. The torn length was 7 cm for all samples.

As it is shown in Fig. 2, the variation of the tearing force during the test has a fluctuating trend.

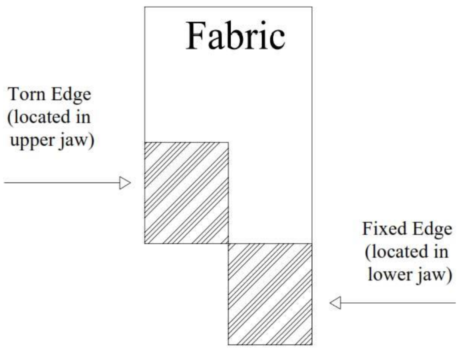


Fig.1. Sample preparation

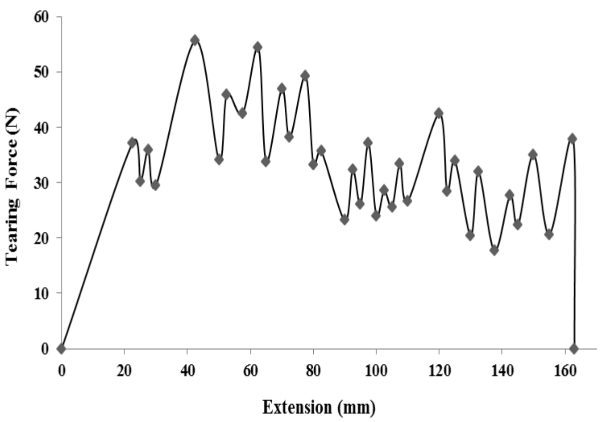


Fig. 2. The variation of tearing force during the test.

In order to study the tearing property of woven fabrics, it was preferred to report a single, precise and comprehensive parameter, which was capable of showing the static tearing behavior of the fabrics correctly. In this regard, the energy consumption for tearing of the fabrics was selected for the evaluation of the tearing characteristic of the fabrics. To calculate the tearing energy it was necessary to identify the upper and lower force peaks (F_{max} and F_{min}) on the tearing diagram and the total area under the tearing diagram. When the tearing force is exerted to the yarns located in the tearing path, the load increases to F_{max}, and after the rupture of yarns the load suddenly decreases to F_{min}. The ability of constituent yarns to make a group and their properties such as flexibility and elongation against load, determines the value of F_{max}. The area between each consecutive peak (F_{max} and F_{min}) can be regarded as a trapezoid. Thus, the total tearing energy (TE) is calculated from Eq. (1):

$$TE = \sum_{i=0}^{n} \left(\frac{(F_{i\max} + F_{i\min}) \times \Delta l_i}{2} \right) \quad (1)$$

where TE is the tearing energy, i is the peak number, F_{imax} is the maximum tearing force in the i_{th} peak, F_{imin} is the minimum tearing force in the i_{th} peak, and Δl_i is the movement of Instron jaws between F_{imax} and F_{imin}.

Since the number of peak points is not equal for various samples, the value of TE, which was calculated from Eq. (1), was divided by " i " for each sample and in this manner the data were normalized and used for the analysis and comparison of results. The experimental results will be discussed in the following sections.

III. Results and Discussion

The results obtained for the tearing energy (TE), using the method mentioned above, are shown in Table II. For the set of fabrics which were used in this study, the value of TE varies in the range of 43.21 mJ for the fabric with the lowest tearing resistance to 321.23 mJ for the most resistant fabric during tearing.

The values of tearing energy for different weft yarn types and weave structures show a special trend, which will be discussed in the next sections.

In order to analyse the concluded data statistically, SPSS software was used. The results revealed that at the confidence range of 95%, the effect of weft yarn type and weave structure is significant on the tearing energy of the worsted woven fabrics.

A. Effect of Fabric Weave Structure on the Tearing Behaviour

The analysis of the tearing results was carried out in order to study the influence of fabric weave structure on the tearing energy of the tested fabrics. In this regard, the diagram of the tearing energy for different weave structures was plotted.

As it is clear from Figs. 3 and 4, for all types of weft yarns that were investigated in this study, hopsack 2/2 had the highest value of tearing energy. The estimated tearing resistance for twill 2/2 was more than twill 2/1, while plain had the lowest tearing strength among other structures. It should be mentioned that similar trends were obtained for both finished and unfinished fabrics.

In order to study the reason of this trend the effect of different structural parameters were examined. It was concluded that the explanation of this trend is related to the firmness of the fabric structure. In order to express the firmness of the fabrics, the parameter of crossing over firmness factor (CFF) of fabric, introduced by Morino *et al.* [18], was used.

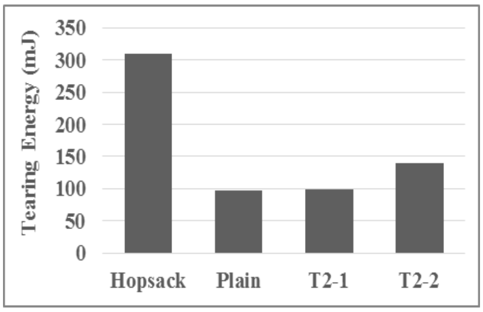
This factor (CFF) is expressed as Eq. (2):

$$CFF = \left(\frac{number\ of\ \ crossing\ over\ lines\ in\ the\ complete\ repeat}{number\ of\ \ interlacing\ \ points\ in\ the\ complete\ repeat} \right) \quad (2)$$

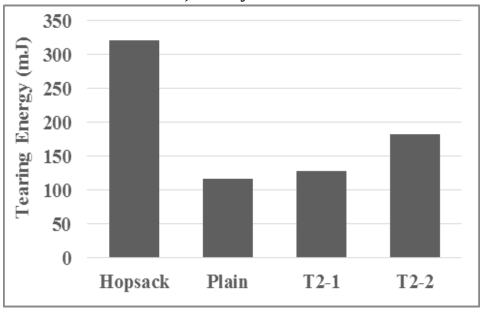
By employing this equation, the value for hopsack 2/2, twill 2/2, twill 2/1 and plain were 0.5, 1, 1.6 and 2, respectively. By increasing the value of CFF, the firmness of the fabric increases, thus the ability of yarns to move and change their position in the fabric structure diminishes. Since the hopsack 2/2 fabrics have the lowest value of CFF, during the exertion of tearing force the yarns in the fabric structure can easily move and gather with the yarns, which are in the vicinity of them; and therefore, make new groups consisting of more than one yarn. In this case the applied tearing force should overcome the breaking strength of the group of yarns, so the value of tearing energy increases. Considering Figs. 3 and 4, it can be concluded that by decreasing the value of CFF, the chance for grouping of yarns in the fabric structure improves and leads to the increase in the fabric tearing strength. The presented explanation is in accordance with the obtained tearing energy values for various weave structures.

TABLE II
TEARING ENERGY FOR VARIOUS FABRICS

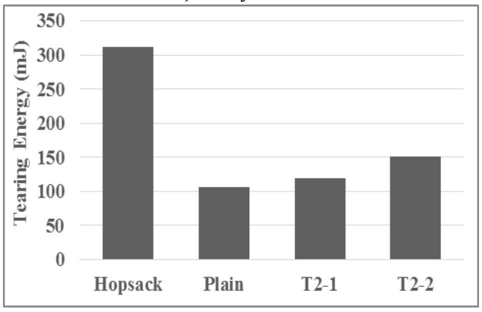
fabric code	weave structure	weft yarn type	TE (mJ) unfinished	TE (mJ) finished
PR1	Plain	R1	97.87	43.21
PR2		R2	117.07	52.22
PSi		Siro	105.76	48.83
PSO		Solo	113.70	50.69
HR1	Hopsack2/2	R1	310.33	222.45
HR2		R2	321.23	270.89
HSi		Siro	312.14	240.01
HSO		Solo	315.79	264.28
T1R1	Twill2/1	R1	98.81	59.23
T1R2		R2	128.04	74.28
T1Si		Siro	119.17	65.24
T1SO		Solo	124.46	69.32
T2R1	Twill2/2	R1	139.29	78.67
T2R2		R2	182.52	99.87
T2Si		Siro	150.85	81.05
T2SO		Solo	163.74	87.19



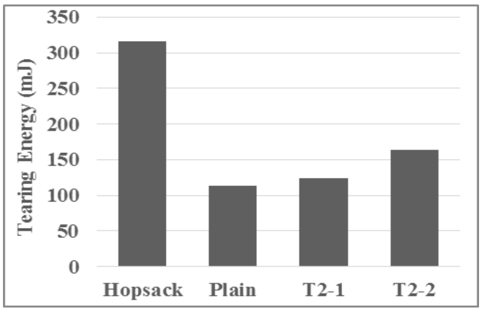
a) weft yarn R1



b) weft yarn R2



c) weft yarn siro



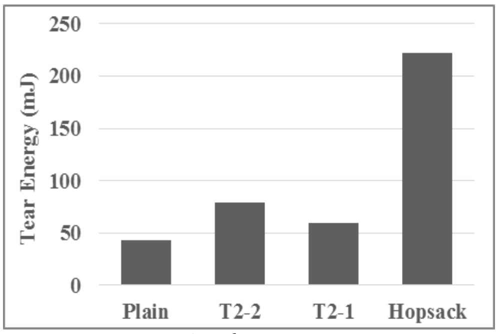
d) weft yarn solo

Fig. 3. The effect of weave structure on fabric tearing energy for unfinished fabrics.

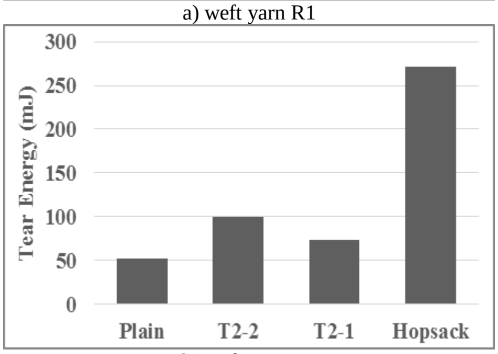
B. Effect of Weft Yarn Spinning Systems on the Tear Behaviour

As it was mentioned before, fabric samples were woven from weft yarns of various structures, which are Solo, Siro, single and two-plied ring yarns. All of the weft yarns have the same yarn count of 26 Nm. In order to probe tearing behaviour of each yarn spinning system, the fabrics tearing energy was measured in the weft direction. The outcomes are presented in Fig. 5.

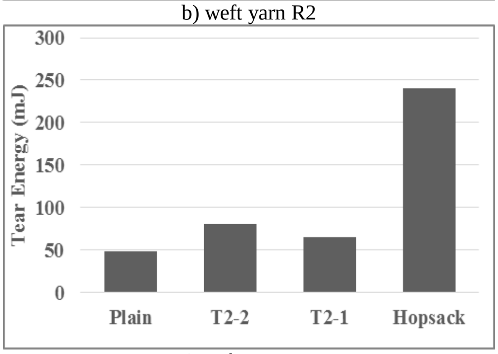
According to Fig. 5, it is seen that in all weave structures, the tearing energy, which is needed, pursues the same trend so that the tearing energy of R2 is more than Solo, followed by Siro and R1, respectively.



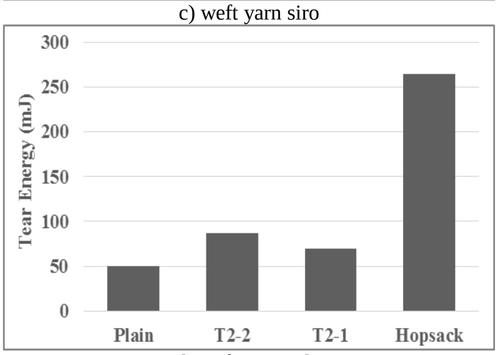
a) weft yarn R1



b) weft yarn R2



c) weft yarn siro



d) weft yarn solo

Fig. 4. the effect of weave structure on fabric tearing energy for finished fabrics.

Although all weft yarns have the same count of 26 Nm, they have different structures. In the two-plied ring yarn, by using two twisted yarns, the two single yarns come together to make a group against the tearing load. So they tolerate the load more and require more tearing force before the rupture. In the case of solo yarns, thanks to the utilization of a special grooved roller, the fibres cooperation in the yarn structure increases which leads to the improvement of the yarn's evenness. Therefore, fibres can participate to the higher effective length in the yarn structure and more tearing load is required to overcome the new made fibres group in the yarn structure. Due to the employment of two strands before twisting the fibres, Siro yarn modifies the yarns evenness and fiber partnership; however, its strength is lower than Solo yarn. Single ring yarn has the lowest tearing energy in all weave structures. It is noticeable that in all weave structures the tearing energy of R2, Solo and Siro have smaller differences compared to R1. This means that using plied yarns or special yarn structure, in which fibers are divided into various groups before the twisting process is effective in the improvement of yarn elongation and endures the tearing force.

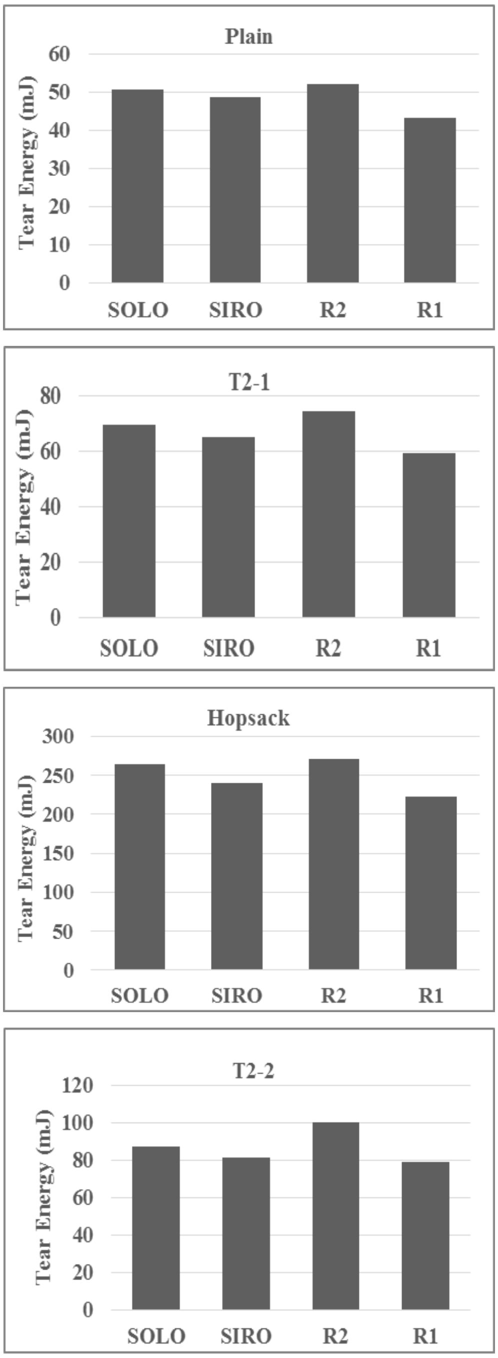


Fig. 5. The effect of various weft yarn structure on the tearing energy.

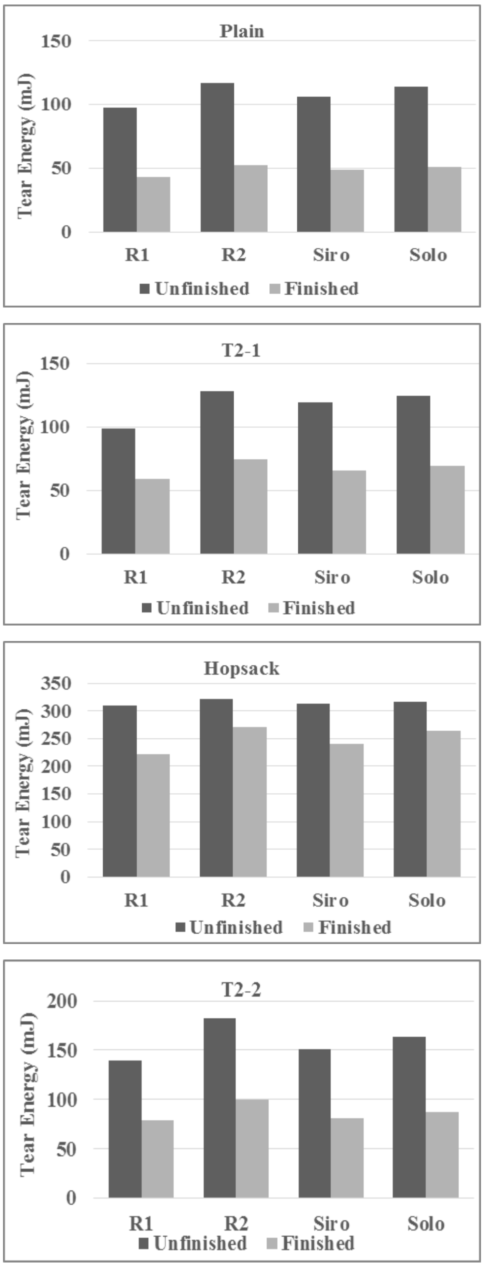


Fig. 6. The effect of finishing process on the tearing energy in the term of weft yarn spinning system.

C. Effect of Finishing Process on the Tearing Behaviour

The finishing process is a crucial procedure in the manufacture of worsted fabrics. Consequently, the investigation of the industrial finishing process of worsted fabrics on the fabric tearing behavior seems to be necessary, since during the daily usage of these fabrics, each customer may encounter with a propagation of existing tear. In Figs. 6 and 7, the tearing energy of finished and unfinished fabrics is compared for the various weft yarn structures and different weave structures, individually.

In all weave structures, the tearing energy after the finishing process is reduced considerably. However, the same trend is presented for various yarn spinning systems; the tearing energy of R2 is more than solo and then siro and R1 stand on the third and fourth position respectively.

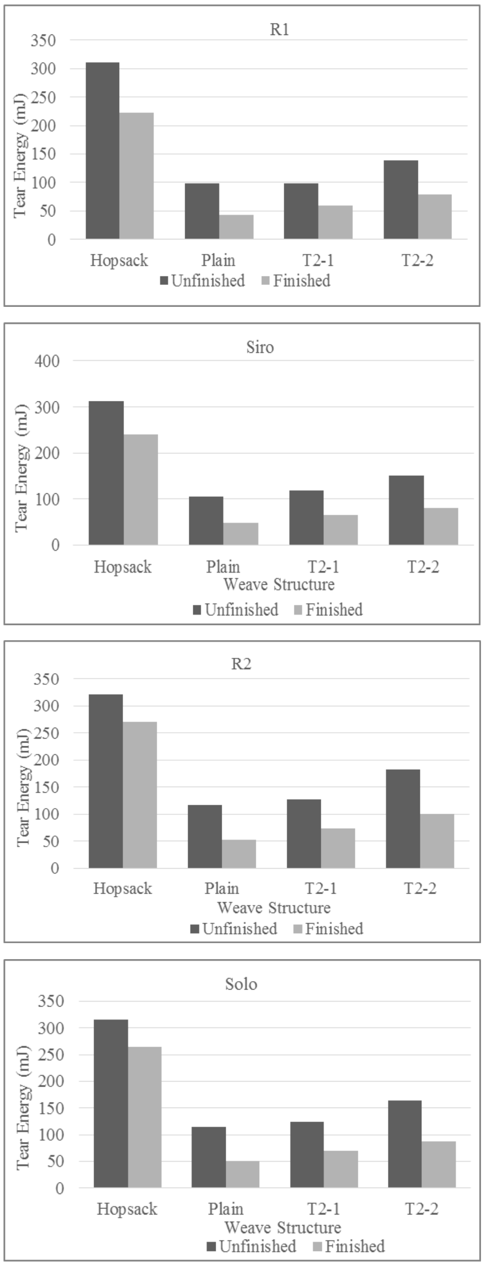


Fig. 7. The effect of finishing process on the tearing energy in the term of weave structure.

This trend is related to the structural variation made by the finishing process such as the fabric density increment and yarn weakness. Fabric density increment leads to the lower fabric load toleration and elongation against the tearing load, which leads to rapid fabric rupture under the tearing load. Furthermore, chemical and mechanical finishing processes lead to the weakness of wool fibers and yarns, which in turn lead to the fabric weakness.

In addition, the tearing energy trend for various weave structures with a certain weft yarn is similar to unfinished fabrics; tearing energy of hopsack 2/2 is greater than twill 2/2, followed by twill 2/1 and plain.

III. CONCLUSION

In the present work, the tearing performance of worsted woven fabrics was investigated. In this consideration, a single and comprehensive parameter, which is the energy consumption for tearing (*TE*) was introduced for the identification of the static tearing behavior of these fabrics.

Statistical analysis of results show that at the confidence range of 95%, the effect of weft yarn type and weave structure is significant on the tearing energy of the worsted woven fabrics.

Besides, it was concluded that among various weave structures that were studied in this paper, hopsack 2/2 and plain had the highest and lowest tearing resistance, respectively. This trend can be interpreted by considering the fabric firmness in various structures. Moreover, the results that were obtained from tearing tests clarified that in a comparison of different yarn types, the fabrics made of two-plied ring yarn in the weft direction had the highest tearing energy followed by the solo, siro and single-ply yarns.

Similar trends were achieved for both finished and unfinished fabrics, but it should be mentioned that the value of tearing energy of grey fabrics was higher than that of finished fabrics.

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