An innovative Method for the Construction of woven flat flexible Cable (FFC)

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Abstract:
Technical textiles have become an innovative area and these developments are due to the technological improvements and researches that have been undertaken in this field. They have entered our life extensively, though we may not be aware of the extent of their usage; for example, fibres reinforcement for composites, cushioning, fillings, electrical components, insulation, sport equipments, toys, automotive, shoe components, insulations, cleaning wipes, personal and medical disposables furniture industry and PVC coating substrates. This paper aims to utilize of the special characteristics of weaving fabric structures in the manufacturing of electrical components. The flat flexible cable (FFC) has been chosen for this research, owing to its prevalence and importance in various branches of projects, aerospace and military fields of effort as well as industrial-commercial programs. Generally, cables conduct electricity from the substation where power is taken from the utility-company lines to the point of utilization. The flat cables are commonly used on machinery such as shuttle cars in mining industry that have cable-reeling devices /1/. The flat shape allows increased length on a cable reel and is less susceptible to run-over damage. On the other hand, flat cable often found in high density electronic applications like laptops and cell phones. Cables designed for small signals, e.g. data bus cables carrying digital data, are screened to prevent their signals from being affected by electromagnetic interference. Cables that carry high power and/or high frequencies are also shielded to prevent them being the cause of electromagnetic interference. The main problem of this research is limited in the difficulty of weaving electrical wires on the weaving machine, and also the choice of the innovative fabric structure. To achieve these aims, the research methodology has to be determined as follows: 1. Study of the characteristics and types electrical cables. 2. Finding the best technical solutions for the weaving procedures. 3. Create an integrated scientific technique beginning of the selection of the materials, fabric structures and preparation of the weaving machine and development of all scientific solutions to overcome the expected operational problems. 4. Weaving process for the experimental samples, as well as the quality control of the weaving process and review the operation program. 5. Discuss the research results, conclusions and recommendations for best weaving method to enhance the characteristics of flexible flat cable (FFC).

1. Introduction

The integration of science, technology and production makes the relationship between them much closed and increasingly dependent on each other. Technological progress is growing day by day to provide the world with the new innovative products in all areas of technology with a view to the happiness and comfort for the mankind. Synthetic fibers opened up completely new application areas for technical textiles. In view of fact, they offered high strength, elasticity, uniformity, chemical resistance, flame resistance and abrasion resistance among other things. These advanced characteristics help the designers to tailor their products for special applications.

The technological advances give an impetus to the technical textiles to affect in various industries. From this practical point of view, the flexible flat electrical/data cable has been chosen as one of the most important electrical component to be developed by using weaving process.

The main goal of this research is to find an innovative manufacturing method for the flexible flat cables which carry small signals, e.g. data bus cables digital data. On the other side, it introduces woven flat flexible cable (FFC) can be safely used

as an electrical component.

Thousands of *cable* types are *used* throughout the world in providing electrical, telephone, and data communications services. Electrical conductors that are commonly used include single solid or stranded wire, twisted pair and trio, multi-conductor *cables*, coaxial *cable*, ribbon *cable*, and *flexible flat cable* /2/.

In the first instance, it is need to make a distinction between wires and cables. Wires are formed from a single solid conductor or stranded conductors, contained within insulation and protective sheath materials.

Cables can be defined as:

• Two or more separate wires within the same insulation and protective sheath

• Two or more wires twisted together

• Any number of wires covered by a metallic braid, or sheath

• A single insulated conductor covered by a metallic outer conductor (co-axial cable) /3/.

2. Background

Electrical wires and cables have to be treated as an integral part of the devices requiring careful installation; this is followed by direct ongoing inspection and maintenance requirements. Wire and cable installations cannot be considered (or treated) as 'fit and forget'. System reliability will be seriously affected by wiring that has not been correctly installed or maintained. Wires and cables that carry high power and/or high frequencies are also shielded to prevent them being the cause of electromagnetic interference. On the other hand, they are also designed for small signals, e.g. data bus cables carrying digital data, are screened to prevent their signals from being affected by electromagnetic interference /3/.

2.1 Types of electric wires and cables

There are different types of electrical cables used for different applications, but two types of electrical cables are commonly used:

2.1.1 Round cables

Round cables feature insulated wires in a bundle which is surrounded by several layers of other material. The bundle is usually wrapped in either a textile material or a polymer chosen to minimize frictional heating as the cable moves. A problem with this construction is its use of multiple layers of insulation and special low-friction materials necessary to reduce the friction that arises as cables go through numerous cycles of repetitive motion.

A PVC jacket surrounds these layers. In shielded cables as illustrated in Fig. 1, there is an additional set of layers consisting of another low-friction wrap, braided copper, and an overall jacket of PVC or other material selected for abrasion resistance. A problem with this construction is its use of multiple layers of insulation and special low-friction materials necessary to reduce the friction that arises as cables go through numerous cycles of repetitive motion.
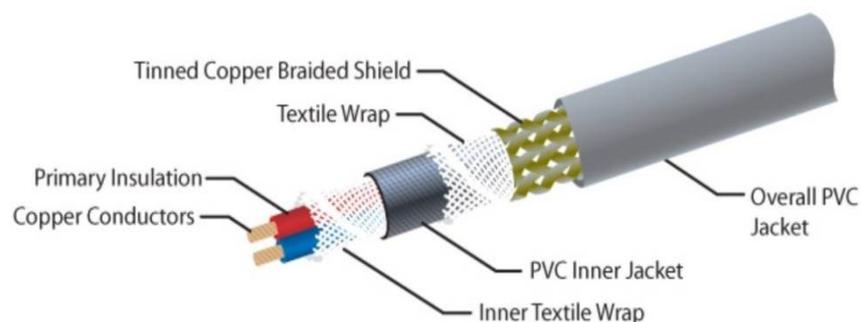

Fig. 1: Shielded cable /4/

2.1.2 Flat flexible cable (FFC)

Flat Flexible Cable (FFC) is made up of thin rectangular copper conductors laminated between two layers of polyester insulation as represented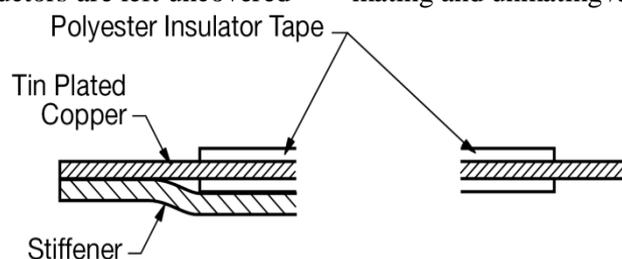 in Fig. 2. These copper conductors are left uncovered on each end and then tin plated to make electrical contact with the connector. A stiffener is bonded to the cable end which provides mechanical stability for the exposed copper conductors during mating and unmating /5, 6/.

Fig. 2: Flat flexible cable /2/

Flexible flat cable (FFC) refers to any variety of electrical cable that is both flat and flexible. A

flexible flat cable is a type of flexible electronics. However, the term FFC usually refers to the extremely thin flat cable often found in high density electronic applications like laptops and cell phones. For optimal flexibility, *cable conductors are composed of many wires combined into* strands, and a number of *strands combined* to *form* the *conductor*.

2.2 Characteristics of electric flat flexible cables

There are many characteristics must be existed in the flat cables, for example:

• Reliability

The simplicity of flat cable with its parallel conductor geometry eliminates many of the common sources of wiring error and malfunction.

• Weight Reduction

The use of flat cable often eliminates much of the conventional wire weight. Such things as redundant insulating materials, fillers and tapes are not required.

• Space Efficiency

A rectangular cross-section allows flat cables to stack with almost no wasted dead space between cables, providing maximum conductor density for a given volume.

• Flexibility

Flat cable is extremely flexible when bent in the plane of its thin cross-section. This flexibility has been utilized in applications where continuous or high flexing is necessary, e.g. drawers, doors, rotating arms, etc.

• Greater Strength

Strength is enhanced by the fact that all conductors and insulation equally share tensile loads.

• Consistent Electrical Characteristics

Because the conductor spacing is fixed and the geometry of the cable is constant, the electrical characteristics, such as impedance, capacitance, inductance, time delay, crosstalk and attenuation, are consistent.

• Greater Current Carrying Capacity

Flat cables have greater surface-to volume ratio than their round cable counterparts, consequently having higher efficiency in dissipating heat. This allows a higher current level for a given temperature rise and conductor cross section.

• Reduced Skewing Effects

Due to the conductors having the exact physical and electrical length, along with a continuous and consistent dielectric, time delays between signals within a given flat cable are minimized.

• High-Density Interconnections

The cabling density achievable using flat cable is superior to that using conventional cable because of the high wire-to-cable cross-sectional density. Layers of flat cable are more effectively packed for higher conductor density than round cable.

• Ease of Handling

Flat cable folds and bends readily, conforms to the mounting area, fastens easily with clamps, adhesive, or double-faced tape, and eliminated the installation and lacing difficulties associated with round wire cabling.

3. Methodology

3.1 Analysis of the Problem

The main goal of the research is to make a combination between the electric cables and warp and weft yarns on the weaving process to produce a *composite-material* structure as a flat flexible cable. The flexibility behavior of the flat flexible cable has to be enhanced by the woven structure elements. The flat form factor of cables also provides better heat dissipation than round cables because there is more surface area for a given volume. The larger surface area lets flat cables carry a higher current level for a given temperature rise and for conductors of a given cross section. The main research problem was enclosed in the rates of elongation of the electric wires, as anyway the elongation rates would not be exceeded than zero percent. This main reason is due to prevent the shed formation and the weaving process couldn't be completed as usual.

3.2 Theory of technology

Electrical flat flexible cables are exposed to wear, tear or deform during a lifetime of more than 10 million cycles, and will withstand repetitive exposure to severe vibration, shock, flames, electrical and mechanical stress, humidity, steam, weld spark, temperature extremes (-65°C to +260°C), oil, water and many chemicals /4/. In the most applications, the flat flexible cables undergo bending; due to this fact their constructions must maintain the minimum values of bending rigidity as possible.

For all these reasons, they have to be designed to provide premium current carrying capacity, excellent heat dissipation, maintaining electrical characteristics, light weight, less stiffness, space savings and are ideal to meet the reliability.

To achieve these goals, the woven flat flexible cable must be designed taking into consideration its structural details. The fabric geometry should be built to give the best required properties as mentioned before for its different applications. Furthermore, the weaving method presents a method of manufacturing shielded flat cable comprising a plurality of tape form conductors, arranged as warp yarns in a narrow fabric (in max. 120 mm. width) /7/. Warp and weft yarns in the woven FFC would be represented the insulation cladding which covers the surfaces of the conductors. In any case, covering the electric wires (conductors) with textile materials will be had a greater physical strength than the normal

insulation cladding.

3.3 Development of woven structures of the electric flat flexible cable

The innovative structure of flat flexible cable was enclosed in using double-layers fabric-structure. This fabric-structure consists of two layers, the face and back-fabrics maintain the required physical properties. On the other side, the electrical wires have to be passed-through as stable wadding layer in middle-space between face and back layer-fabrics as shown in Figure 3.
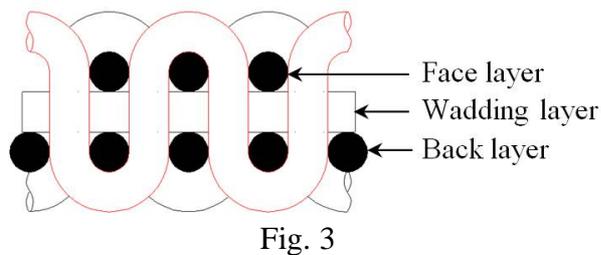

Fig. 3

The experimental work has to be carried out by using PES textured yarns (C.F) for warp and weft yarns, which must be treated against fire and heat. This chemical-treatment have to be achieved before weaving process, the treatment prevents the flat cables from bad effects which could be exposed to it.

3.4 Development of weaving process

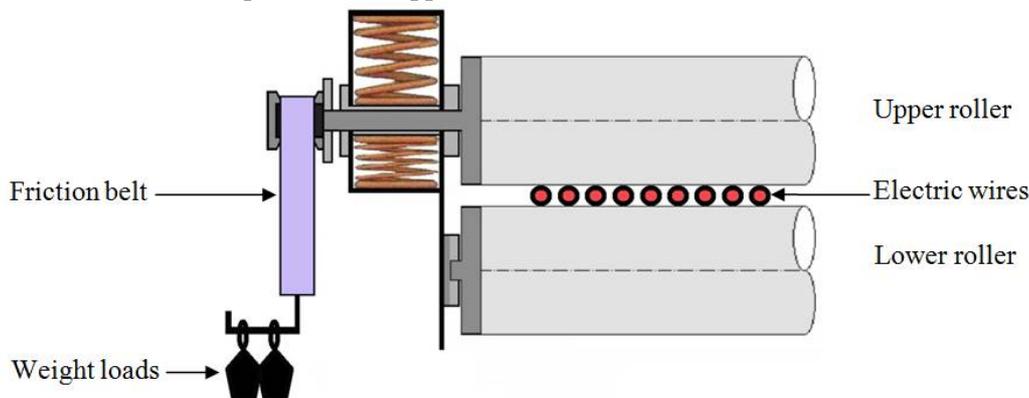The experimental work has to be carried out by using two-weft needles technique which is applied in narrow weaving machine of J. Müller, two sheds are formatted; hence two wefts are inserted simultaneously for the upper, and lower fabrics. Four layer-positions are required for the warp yarns (upper, middle and lower) with maximum 20 heald frames. Some procedures have to be achieved on the weaving machine to overcome the stiffness of the electric wires.

These procedures can be defined as follows:

1. One warp beam would be used for PES textured warp yarns (C.F), this warp beam for the face and back-fabrics.
2. For the electrical wires, cones creel must be used, hence they had to be drawn in stable heald-frame in the middle position all the time during the weaving process.
3. A developed let-off device has to be built-in on the weaving machine in the distance between the cones creel of electrical wires and the healds frames. The function of that device is to control the movement of electric wires during weaving-process. Figure 4 shows the developed let-off device which consists of two steel rollers on each other and weight units have to put on the ends of upper roller to control the let-off motion of the electric wires. The weight load units have to be determined depending on the fabric structure and the exchanged forces during the weaving-process.

Fig. 4:The developed let-off device which controlled the movement of electric wires

Finally, the research samples have to be tested and analyzed. The statistical analysis of the laboratory tests results helps to organize data and focus the light on the weak and strong points in the research variables. It helps also in studying the results with a view to help in the future improvement of the fabric specification.

4. Experiments

The ***experiments*** have been ***carried out*** on narrow weaving machine (J. Müller Company) with face-to-face weaving technique. With this technique two-weft needles and two sheds are formatted; hence two wefts are inserted simultaneously for the upper and lower fabrics. On the other side, the machine equipped for inserting double wefts in one shed during weft insertion. Three layer-positions are available for the warp yarns (upper, middle and lower) with maximum 8 heald frames. There are also two layer-positions are available (upper and lower) with maximum 12 heald frames.

4.1 Weaving procedure

The experimental samples had been woven by using PES textured yarns for the warp and weft yarns and electric wires as wadded warp yarns. The specimens´ constructions are based on the double-weave tying from warp and weft yarns. The main elements of woven fabric structures variables were:

1- Fabric construction, (plain weave 1/1, twill weave 2/2, twill weave 1/3) on the basis of double-weave tying from warp and weft yarns.
2- Warp yarns density (28, 56) yarns/cm.
3- Wefts density (10, 12, 14) wefts/cm.

The structural elements of the woven flexible flat electrical/data cable is represented in Tab. 1. On the other side, Tab. 2 illustrates the structural elements of the master sample which were woven by using square set of warp and weft yarns has determined in 28 yarns and wefts/ cm.
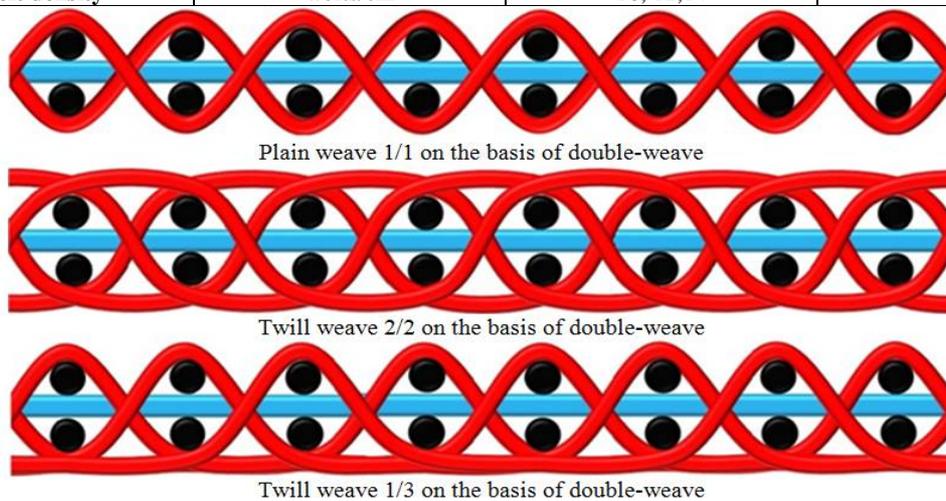
Fig. 5 shows the cross-sections in the warp direction for the fabric constructions of the flexible flat electrical/data cable. Fig. 6 shows a comparison between the commercial flat electrical/data cables as illustrated at A and B, on the other hand Fig. 5C represents the innovative product which had been developed in this paper.

Table 1: The first structural elements of the woven flexible flat electrical/data cable
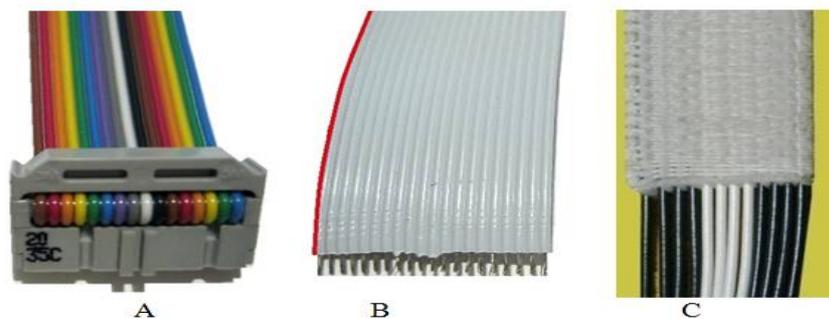
		Ground fabric	**Wadding-yarns (Wires)**
Materials	Warp & weft yarns	**PES textured yarns**	**Electrical wires**
	Count in denier	150 den	-
Sample width	(in the reed)	60 mm	
Warp density	No. of all yarns and wires	168 yarns	12 wires
	yarns/cm or wires/cm	28	2
Draft system	No. of healds	8 healds	1 healds
Denting system	Reed 9 (dent/cm)	4 yarns/dent	1wire/dents
Weft density	wefts/cm	28	

Table 2: The structural elements of the master sample woven flexible flat electrical/data cable

		Ground fabric	**Wadding-yarns (Wires)**
Materials	Warp & weft yarns	**PES textured yarns**	**Electrical wires**
	Count in denier	150 den	-
Sample width	(in the reed)	60 mm	
Warp density	No. of all yarns and wires	168 yarns	336 yarns
	yarns/cm or wires/cm	28	56
Draft system	No. of healds	8 healds	1 healds
Denting system	Reed 9 (dent/cm)	4 yarns/dent yarns/dent	8 yarns/dent
Weft density	wefts/cm	10, 12,14	

Plain weave 1/1 on the basis of double-weave

Twill weave 2/2 on the basis of double-weave

Twill weave 1/3 on the basis of double-weave

Fig. 5: The cross-sections in the warp direction for the fabric constructions

A   B   C

Fig. 6: A comparison between the commercial FFC at A and B, and the innovative product at C

4.2 Laboratory tests

Laboratory tests had been performed in accordance with standard procedures which are recommended by the American Society for

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Testing and Materials (ASTM) D 1388, "Stiffness of Fabrics" and D 3776, "Standard Test Method for Mass per Unit Area (Weight) of Fabric" /8/. The laboratory tests have been carried out on measurement of bending length and flexural rigidity has to be calculated for the experimental samples. This test is employing the principle of cantilever bending of the fabric under its own mass.

The "cantilever bending length" is a measure of the tendency of a horizontal strip of fabric to bend under its own weight, for a fixed distance. It is simply measured by sliding a strip of the fabric over the edge of a horizontal surface until gravity causes the strip to bend to a prescribed angle as shown diagrammatically in Fig. 7B /9/. The test specimens are each 25mm wide and 200mm long; three are cut parallel to the warp and no two warp specimens contain the same warp threads. The specimens should not be creased and those that

tend to twist should be flattened. Four readings are taken from each specimen, one face up and one face down on the first end, and then the same for the second end.

The mathematics of the bending length test has been worked out so that the length of overhanging fabric (o) as illustrated in Fig. 8. Furthermore, it has found that when the tip of the specimen reaches a plane inclined at 41.5° below the horizontal, the overhanging length is then twice the bending length /9/.

Flexural rigidity G can be calculated according to the formula:

$$G = wc^3 \qquad (1)$$

with: w - fabric weight per unit area (mg/cm^2)

   c - bending length (cm).

and then:

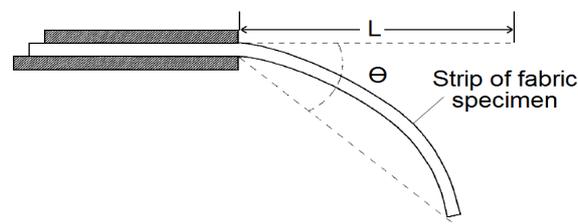   G - values are expressed as mg.cm, and thus are units of torque /9/.

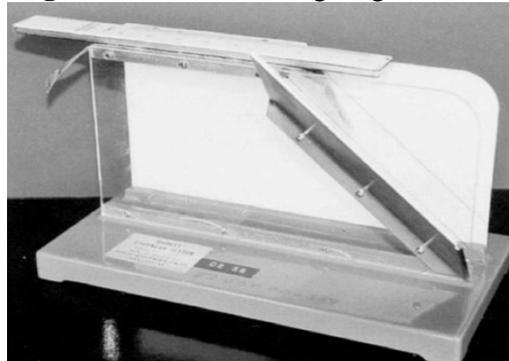**Fig. 8**: Cantilever bending length test /10/

Fig. 7: The Shirley stiffness test, Cantilever Test Apparatus /10/

4. Results and discussions

The goal of this research is to manufacture an innovative woven flexible flat electric cable (FFC); this type of cable must be more flexible than the traditional similar products in the trade markets. This woven flat flexible cable has to be used with high rates of safety and functional using. This cable with its distinguishing characteristics could be employed in many fields, e.g. as connection cables of shuttle cars in mining industry and also as an electrical component carry small signals data bus and digital data.

To achieve these aims, it has been taken into consideration that the final product which is woven flat flexible cable (FFC) must have the lowest stiffness values to guarantee flexibility, high duty and also safety. The methodology of the

experiments built in strategy plan which depends on that the physics of fabric constructions play a critical role in its stiffness behavior.

To recognize the influence of different fabric constructions on the stiffness behavior of the FFC cables, many procedures have been achieved to study the effect of the fabric-structure parameters on the fabric stiffness. These procedures were verified by the laboratory tests which enclosed in specimens´ weight and bending length in the warp direction, as well as, the warp yarn crimp percentage has been tested manually. Finally, the flexural rigidity values in the warp direction for the specimens have been calculated mathematically.

The comparisons have been achieved between the laboratory tests and the variables of structure-

elements of the experimental work which determined in the plain weave 1/1, twill weave 2/2 and twill weave 1/3 which have been woven by using two warp densities enclosed in 28 and 56 yarns/cm, in addition to using three weft densities enclosed in 10, 12 and 14 wefts/cm. on the other side there are three specimens have been woven as maser samples for the comparison study by using fabric square set (28 yarns/cm and 28 wefts/cm).

Referring to the laboratory results, Table 3 represented a comparison between the weight values per unit area in mg/cm^2 for the specimens with their variables of structure-elements as mentioned above, from this comparison; it was found that the weight values were changed according to the change in fabric construction. The plain weaves 1/1 achieved the highest values of weight follow with twill weaves 2/2 and twill weaves 1/3 achieved the lowest values of the

weight. There were also higher differences between the average values of the weight for plain weaves 1/1 than the other weaves with the similar fabric-structure parameters. The increasing averages in the weight of plain weaves 1/1 were approximately 15% more than the twill weaves 2/2 and 20% the twill weaves 1/3. There were high increasing in weight values according to the increasing in warp densities with high differences for all fabric-constructions. There were normal and low increasing in weight values according to the increasing in weft densities for all fabric-constructions when the warp density became invariable as shown also in Fig. 10. The highest value of weight has been achieved by using plain weave 1/1 with 56 warp yarns/cm and 14 wefts/cm, and the lowest value achieved by using twill weaves 1/3 with 28 warp yarns/cm and 10 wefts/cm.

Table 3: The results of weight values for the specimens with variables of structure-elements

| Warp density (Yarn/cm)		Plain weave 1/1	Twill weave 2/2	Twill weave 1/3
	Weft density	Weight per unit area (w) [in mg/cm^2]		
28	10	43,197	39,780	38,012
	12	45,808	41,078	39,230
	14	48,287	42,654	40,728
	28	66,578	55,154	52,662
56	10	57,994	51,159	48,857
	12	62,536	53,077	50,696
	14	66,815	55,547	53,008

It is observed from Table 4 and Fig. 11, considering the influence of fabric-constructions, warp and weft yarns densities on the bending length in the warp direction that the plain weaves 1/1 achieved the highest values of bending length follow with twill weaves 2/2 and twill weaves 1/3 achieved the lowest values of the bending length in the warp direction. There were also very high differences between the average values of the bending length of plain weaves 1/1 and the other weaves with the similar fabric-structure parameters. The increasing averages in the bending length of plain weaves 1/1 were approximately 8% more than the twill weaves 2/2 and 10% the twill weaves 1/3. There were a normal increasing in the bending length values according to the increasing in warp and weft densities, but the differences related to the weave-construction or warp yarns densities were recorded more values than the differences in weft densities. The highest value of bending length in warp direction has been achieved by using plain weave 1/1 with 56 warp yarns/cm and 14 wefts/cm, and the lowest value achieved by using twill weaves 1/3 with 28 warp yarns/cm and 10 wefts/cm.

From these results which are mentioned above, it was also found that there were higher differences between the results of plain weave 1/1 from one

side than the differences between twill weaves 2/2 and 1/3 whether in weight or bending length results from the other side.
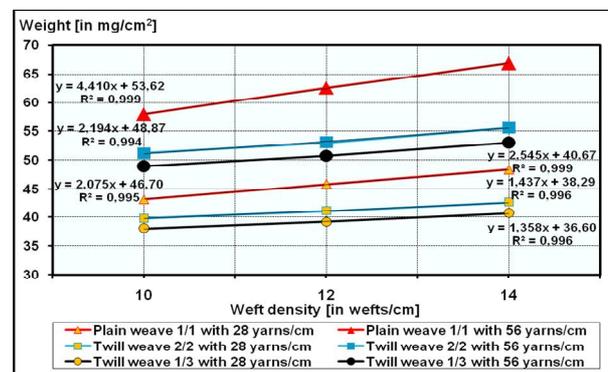
Fig. 10 The relation between the weight values for the woven Cables (FFC) by using different weft densities (10, 12 and 14 wefts/cm), different warp densities (28 and 56 yarns/cm) and different fabrics´ constructions
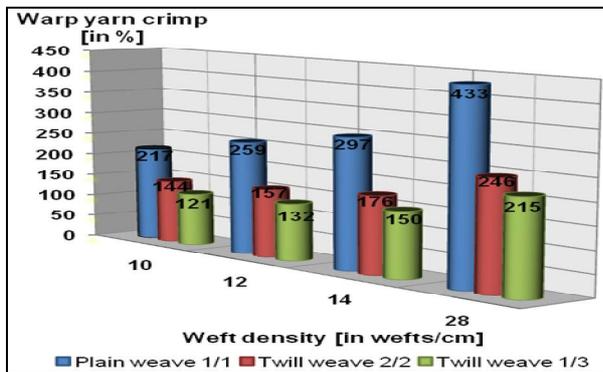
Fig. 9 The relation between the warp yarn crimp percentage by using different weft densities (10, 12, 14 and 28 wefts/cm), warp densities (28 yarns/cm) and different fabrics´ constructions

Table 4: The results of bending length in the warp direction for the specimens with variables of structure-elements

Warp density (Yarn/cm)		Plain weave 1/1	Twill weave 2/2	Twill weave 1/3
	Weft density	Bending length in the warp direction (c) [in cm]		
28	10	3,668	3,268	3,211
	12	3,715	3,434	3,396
	14	3,765	3,604	3,560
	28	4,884	4,662	4,508
56	10	4,826	4,300	4,224
	12	4,888	4,518	4,468
	14	4,942	4,742	4,684

The flexural rigidity in warp direction has been calculated mathematically as previously mentioned according to the formula (1) as shown in Table 5. Referring to these results, it was found that the flexural rigidity values were changed according to the change in fabric construction. The plain weaves 1/1 achieved the highest values follow with twill weaves 2/2 and twill weaves 1/3 achieved the lowest values. There were also higher differences between the average values of plain weaves 1/1 than the other weaves with the similar fabric-structure parameters. The increasing averages in the weight of plain weaves 1/1 were approximately 44% more than the twill weaves 2/2 and 58% the twill weaves 1/3. There were normal increasing in flexural rigidity values according to the increasing in warp densities with high differences and with low differences with the increasing in weft densities as shown also in Fig. 12. The highest value of flexural rigidity in warp direction has been achieved by using plain weave 1/1 with 56 warp yarns/cm and 14 wefts/cm, and the lowest value achieved by using twill weaves 1/3 with 28 warp yarns/cm and 10 wefts/cm as shown in Fig. 12.

Referring to fisher-snedecor's table, it is recalled for the degree of freedom 2, 18, it is found that the $F_{0.95}$ (2, 18) value equals 3.55 at 95% confidence. By applying these values, it was found that the F-values between the different values of flexural rigidity in warp direction are significant differences at 95% confidence level.

Table 5:   The results of flexural rigidity in the warp direction for the specimens with variables of structure-elements[*]

Warp density (Yarn/cm)		Plain weave 1/1	Twill weave 2/2	Twill weave 1/3
	Weft density	Flexural rigidity (G = wc³) [in mg.cm]		
28	10	2131,772	1388,370	1258,482
	12	2348,658	1663,466	1536,454
	14	2577,084	1996,689	1837,572
	28	7756,325	5588,444	4824,448
56	10	6518,443	4067,497	3682,111
	12	7303,424	4894,888	4521,832
	14	8064,560	5923,078	5447,396

* The least significant difference (LDS) at 5% level for all comparisons between values is 3,55
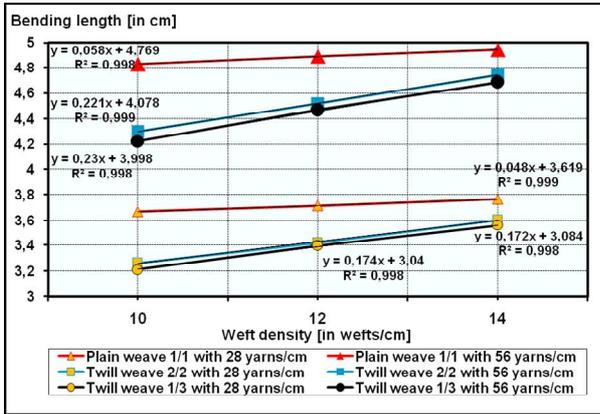
Fig. 11 The relation between the bending length values for the woven Cables (FFC) by using different weft densities (10, 12 and 14 wefts/cm), different warp densities (28 and 56 yarns/cm) and different fabrics´ constructions
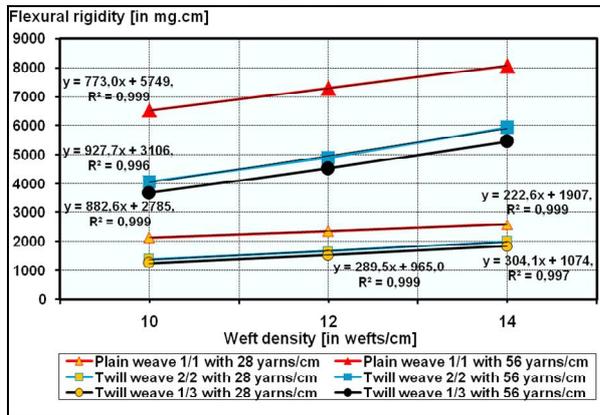

Fig. 12 The relation between the flexural rigidity for the woven Cables (FFC) by using different weft densities (10, 12 and 14 wefts/cm), different warp densities (28 and 56 yarns/cm) and different fabrics´ constructions

As it is known from the equation (1) of flexural rigidity that the weight and bending length of the specimen determine as independent variables which affect positively on the result of the flexural rigidity as a dependent variable. For this reason, it was very important to study the structure-elements parameters which affect on weight and bending length, these parameters have to be nominated as sub-independent variables in this case. These sub-independent variables were affected consequently on the stiffness behavior of the flat flexible cable and its ability to bend.

It was found as mentioned before that the weight and bending length have the same trend of behavior under action of the structure-elements parameters. These results have been studied and the next points put their scientific explanation:

1. 1. The increasing in weft and warp densities leaded to the increasing in weight, bending length and hence flexural rigidity in warp direction for all fabric fabric-constructions. The reason of these normal increasing is related to the progression increasing in weft densities from 10 to 12 to 14 wefts/cm, and also for the

increasing in warp densities from 28 to 56 yarns/cm. The differences in weight values related to warp densities were higher than the differences in weft densities, the reason of that related to the lower increasing in weft densities (two wefts/cm) compared with the higher increasing in warp densities (from 28 to 56 yarns/cm). On the other hand, the warp yarns crimp percentages were ranged from 121% to 297% for the all used fabric-constructions, from 217% to 433% for the specimens with square fabric-set as shown in Fig. 9, and the wefts crimp percentages were not exceeded than 2% owing to the physics of this special type of fabric-structure as it is discussed later. Increasing in warp and/or weft densities were affected positively on the fabric firmness and stability, besides the increasing in the weight, all of that give the specimen additional force to prevent the bending during the test and hence the stiffness behavior has to be increased.

2. In general, the plain weaves 1/1 achieved the highest values of weight 15% and 20% more than twill weaves 2/2 and 1/3 respectively, bending length 8% and 10% more than twill weaves 2/2 and 1/3 respectively and hence flexural rigidity in warp direction 44% and 58% more than twill weaves 2/2 and 1/3 respectively. The differences between the average values of the weight, bending length and hence flexural rigidity in warp direction for plain weaves 1/1 were higher than the other weaves with the similar fabric-structure parameters as mentioned before. The high differences between the results according to the change in fabric-constructions ensure that the plain weave 1/1 is more stiffness than the than twill weaves 2/2 and 1/3, owing to the physics of weave-construction as the following interpretation:

- In plain weave 1/1 each warp and weft threads passes over one thread and under the next, and they interlaced with each other alternately hence it has the maximum number of binding points. It is characterized by highest frequency of interlacing in comparison with other weaves, owing to its highest in crimp values. On the other side, the high degree of crimp increased the weight, stable behavior and good resistant to distortion.

- In twill weave have warp yarn floats on the surface of the fabrics across two wefts as twill weave 2/2 or three wefts as twill weave 1/3, in general have longer floats, fewer intersections and more open construction and hence lowest degree of yarn crimp than a plain weave fabric with the same cloth particulars. On the other side, fewer interfacings reduce the interfiber

friction, which contributes to a greater pliability, softness, and lower values of bending length as illustrated in Table 3 and shown in Fig. 10, hence the stiffness behavior of twill weaves are lower than plain weave 1/1 with similar fabric-structure parameters.

The previous interpretations were confirmed owing the following results:

- The values of flexural rigidity in the warp direction of plain weave 1/1 increased 29% up to 60% compared with twill weave 2/2 and also increased 40% up to 69% compared with twill weave 1/3 with similar fabric set as represented in Table 5 and shown in Fig. 12.

- The values of flexural rigidity in the warp direction of the mater samples with square fabric-set with 28 yarns/wefts were almost equal to the corresponding values for the similar weave-constructions by using double warp density with half weft density, this result related to the equal of number of binding points between them. It ensures that the difference between the weave-structures in stiffness related to the difference of weave-constructions more that other variables.

5. Conclusions

It is expected that soon textiles will be merged with electronics in all areas of uses. The developed woven flat flexible cable (FFC) could be used in the future as a main component of the products which are known as interactive electronic textiles (IET).

Cables need to be physically flexible to allow it to be installed, and then to withstand the vibration of the devices that will cause the wires to flex. Multistranding of the conductor increases the flexibility of the wire or cable, making it easier to install and withstand vibration. The insulating material has to be able to withstand the applied voltage; the sheath material needs to be able to withstand the specified contaminants. Conductors need to be able to carry the required current without overheating or burning; they must also have low insulation resistance to minimize voltage drops. Electrical wires and cables have to be treated as an integral part of the devices requiring careful installation; this is followed by direct ongoing inspection and maintenance requirements.

Wires or cables designed for small signals, e.g. data bus cables carrying digital data, are screened to prevent their signals from being affected by electromagnetic interference. Wires and cables that carry high power and/or high frequencies are also shielded to prevent them being the cause of electromagnetic interference.

Fabric-stiffness is related to the area of fibers employed, which may vary in the warp and weft directions of the fabric. Furthermore, the type of employed weave-constructions and the weaving process will both effect stiffness variations under load due to crimp interchange. Plain weave achieves the high stiffness values more than twill weaves, owing to the increasing in intersections rates between warp and weft yarns which has an effect on the increasing of crimp rates more than other structures, because each warp yarn interlaced with each weft alternately. The stiffness of woven structure depends on the frequency of interlacing between the warp and weft yarns and the number of intersections. The twill weave 1/3 is more suitable weave-construction to use in the woven flat flexible cable, owing to lower stiffness values more than the other constructions in this research.

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