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Fatigue Life Estimation of Circular Knitting Needle †

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Abstract: Needles are the most important stitch formation elements of the knitting process and they are exposed to variable and repetitive loads and forces during fabric production. Stresses that are obtained due to these forces are smaller than the material yield and tensile strength. However, after a while the material cannot carry these dynamic loading they are exposed and finally broken. This is regarded as the fatigue of the needles. Any abraded or fracture of these needles cause unwanted and irrecoverable faults on fabric like uneven loop structure, holes and dropped stitches, which cause huge cost loss. Considering that the number of needles on circular knitting machines (varying from 1000 to 2800 averages depending on machine type) and the average price of 6 Euro/per needle, it is very important to estimate the needle deformation to avoid fabric production faults and reduce the operating costs by extending needle life. From this point, the study was designed to predict the fatigue lives of needles under certain production conditions. To do so, a model using finite element method was developed to determine the forces acting on the needles during knitting production process. The stress values obtained were imported to nCode Designlife program in order to estimate the fatigue damage of circular knitting needle. The results were compared with experimental study and there was a 14.17 % difference between the experiment and program. The model showed that by changing production data, the fatigue lives of the needles, can be determined very quickly at low cost.

Keywords: Needle; knitting; fatigue; nCode; FEM

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1. Introduction

Knitting needles are the main elements for the knitting process and they are continuously in contact with fibers, yarns as well as contaminants existing in the structure of the yarns, cams and slots. The lifetime of knitting needles is an important issue due to high cost of needles in the long term. This is a cause of both cost of changing the needles regularly and losing working time during the changing process. Also any breakages or failures of the needle can cause irreversible errors in the quality of fabric.

Today, the finite element method has become an important tool due to the known disadvantages of experimental studies such as high cost and limited reproducibility. Although it is a tiring process to complete the design stages of the large and complex finite element model analysis, it gives consistent results with experimental studies, flexible enough to easily respond to alternative data inputs during the design and product development stages, and repeatability with much lower costs increases the importance of this method [1]. In addition, the use of finite element analyzes for fatigue and durability tests is becoming more and more common [2].

From this point of view, the main objective of this research was to obtain the forces acting on the circular knitting machine needle by the help of finite element method, and then determining the fatigue life of the needle in accordance with these forces.

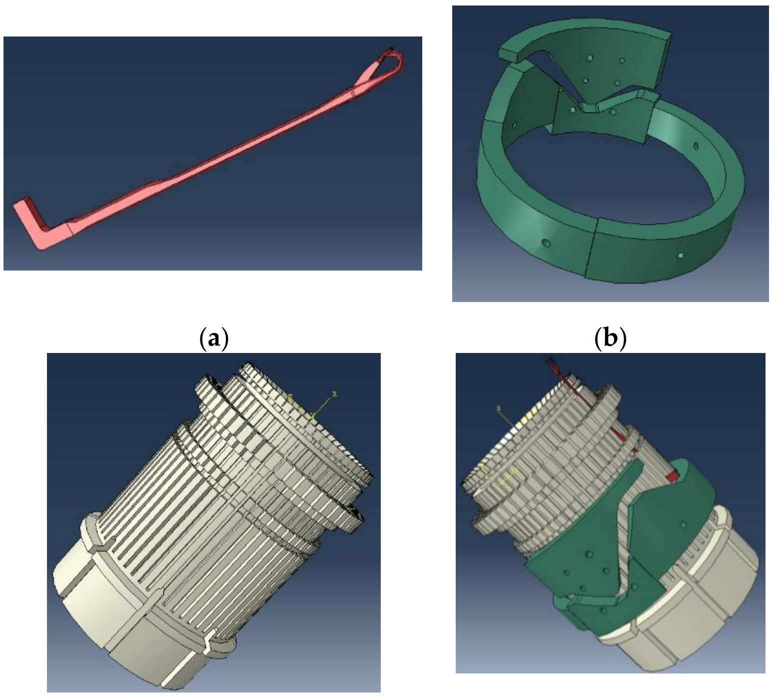
2. Material and Method

2.1. Experimental Study

With the aim of determining the life of the needles, the laboratory type knitting machine, which helps to save material and energy, was employed. The machine was 3.25″ in diameter and had fifty-six needles. During the production process, all the settings were kept constant in order to investigate the lifetime of the needle at standard conditions. The machine had the same equipment such as automatic oil, take up and feeding system, as an industrial one. Before starting the experiment, all of the needles of the machine were replaced with the new ones and the knitting period was ended when a needle breakage occurred. For the study, Ne 4/1 100% cotton open-end yarn was used. In the beginning of the study the machine velocity was adjusted to 100 rpm, but then increased to 250 rpm and finally the velocity was adjusted to 450 rpm (Fatigue is independent from frequency). A positive feeding system was used to supply yarn from side creel to the knitting zone under four grams of tension. The periodic machine maintenance was also applied such that the needles, sinkers, slots and cams were cleaned in detail. Up to needle fracture, three maintenance processes were made.

2.2. Computational Study

In the following section, the 3-dimensional model of the needle used in the study was obtained with the help of a coordinate system while 3-D models of the cam and cylinder of the knitting system were drawn by Solidworks program as shown in Figure 1.

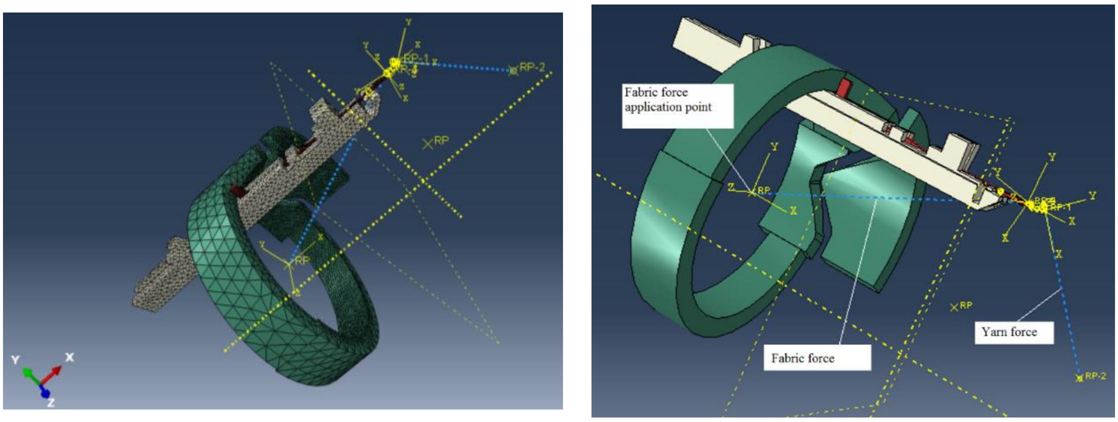


(**a**) (**b**) (**c**) (**d**)

Figure 1. (**a**) 3D image of the needle (**b**) 3D image of the cam (**c**) 3D image of the cylinder (**d**) Assembly of the system.

Then a finite element solver ABAQUS was used to determine the forces acting on the needles during knitting production process. Due to the complex structure of the needle geometry, the mesh size of this element was chosen to be smaller than that of the cylinder and cam parts, and the element type C2D10M "quadratic tetrahedron" was assigned as the element type whereas C3D4 "4-node linear tetrahedron" element type was selected for cylinder and cam parts (see Figure 2a).

Surfaces that are in contact with each other on the 3-dimensional model were defined. The value of the metal-metal friction coefficient of 0.135 obtained from the literature was used in this study [3,4]. The rotational movement was given to the cam by the point which was centrally located in the cam curvature. In order to converge to the actual model, no limitation and boundary condition was set to the degree of freedom of the needle. By this way, the needle was subjected to the reaction forces coming from the cylinder and the cam. Also, the yarn and fabric forces were defined in the model in an attempt to project the reality to the model. Furthermore, t, the weight and inertia forces of the needle were also taken into account in this model (see Figure 2b). The model was defined as a nonlinear explicit dynamic analysis model due to the fact that the needle moves on the cam profile and the cam angle changes at every step.



(**a**) (**b**)

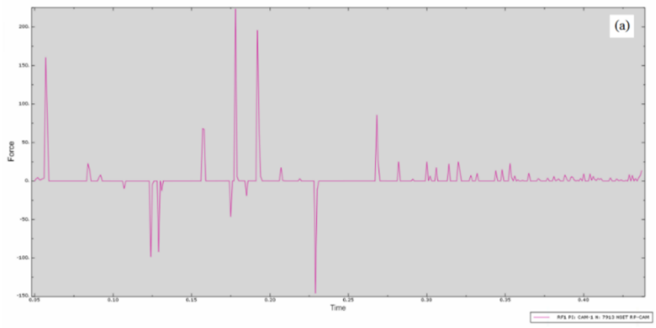
Figure 2. (**a**) Mesh view of the system (**b**) Yarn and fabric forces.

The stress values obtained from finite element method were then imported to nCode Designlife program in order to comparatively study the fatigue lives of the experimental and finite element results.

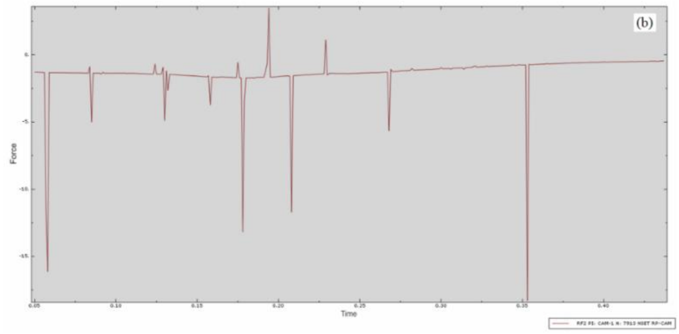
3. Results

3.1. FEM Results

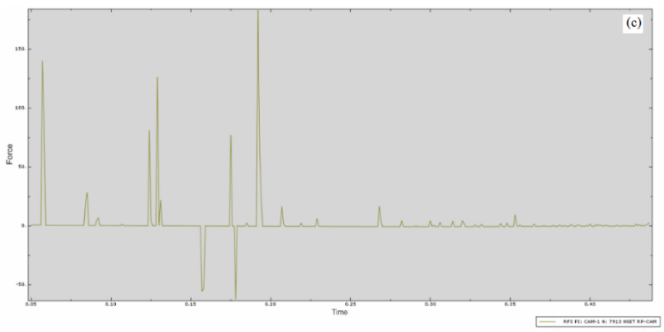
Figure 3 shows the reaction force relationship between the needle and the cam at the conditions of 100 rpm machine speed, 3 cN yarn force and 2.5 N fabric force. Accordingly, during the rotation of the cam around the cylinder, the needle follows the cam profile and make a bouncing motion at various intervals with the effect of the rotation speed. High reaction forces occur at the points where the needle come into contact with the cam again. It has been observed that the resulting forces are more significant and have higher values especially in the vertical direction.



(**a**)



(**b**)



(**c**)

Figure 3. Reaction forces between the needle and the cam: in (**a**) x direction, (**b**) y direction and (**c**) z direction.

3.2. *nCode Fatigue Results*

The finite element model results obtained in Section 3.1 were imported to the nCode Designlife fatigue program and virtual fatigue analyzes were carried out (see Figure 4).

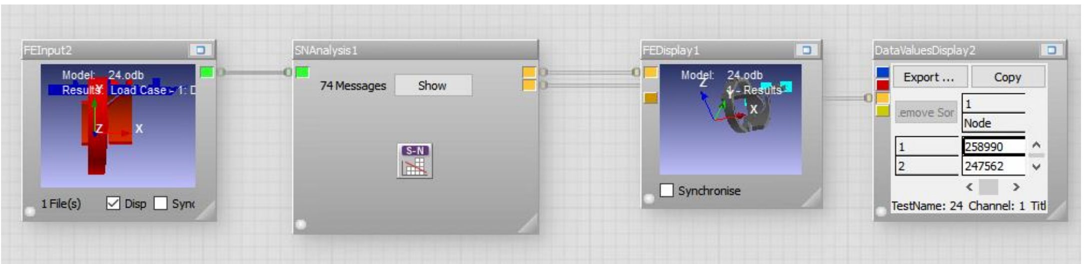
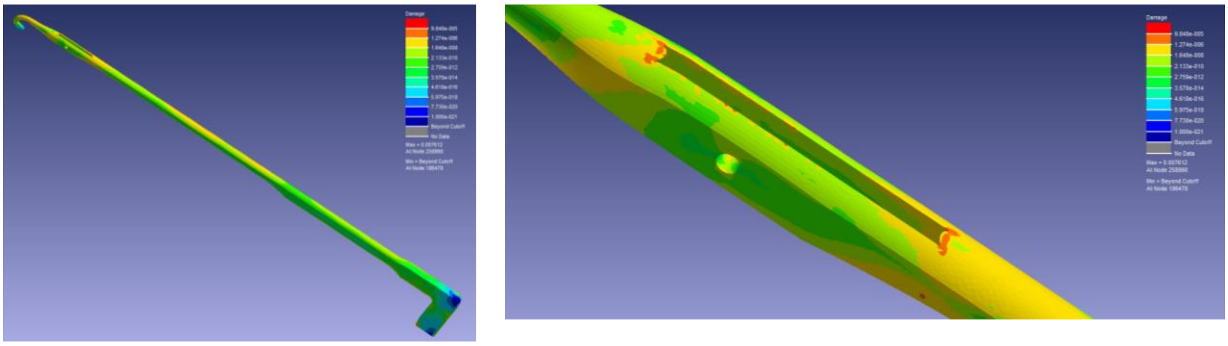


Figure 4. nCode for finite element method.

According to the results obtained from the real-time experimental setup, it was concluded that fatigue was occurred after 10,950,400 repetitions and fractured from the rivet region. With reference to the fatigue results made with nCode, it was observed that the greatest damage to the needle occurred in the rivet part (see Figure 5).



(**a**) (**b**)

Figure 5. (**a**) A close-up view of the needle damage and (**b**) Fracture area.

In the light of these data, the fatigue life of the mentioned fracture zone was investigated. In this direction, lifetime data were collected from the region that was fractured as a result of the experimental study and had the most damage according to the virtual analysis (Figure 6). Accordingly, it was found that the needle has a fatigue life of 11,464,940 repetitions, according to the virtual fatigue analysis made in the nCode Desinglife program. According to the experimental study, it was found that the needle had a fatigue life of 10,950,400 repetitions. Finally, with a 14.17% difference the lifespan of the needles could be estimated. This result can be regarded as a success when the error margin of fatigue life in the literature, which is average 20%, is taken into consideration.

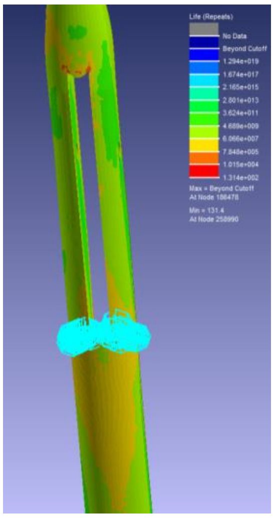


Figure 6. Determination of lifespan from the fracture surface.

The accuracy of fatigue and structural analysis results is directly related to that of the information used in the study. In order to obtain correct results, material properties and loading conditions should be introduced to the model as accurately as possible. The material information of the needle used in the study was calculated empirically. Also, because the fabric take down force cannot be measured directly from the current circular knitting machine technology the approximate data was taken from the literature [5]. It is thought that these two factors have an effect on the resulting difference.

Based on the similarity of the experimental study and the finite element model results, it can be stated that optimization studies can be carried out for different production conditions with the help of finite element analysis. In this way, probable needle damage related problems can be avoided in short time and at low cost.

4. Conclusion

In knitting technology, for the first time nCode fatigue program was used to predict fatigue life of circular knitting needles according to finite element method results. In that respect, this study provides a new scientific understanding, and it represents a great challenge as well as significant contribution to knitting machine industry. Having said that, it may be concluded that finite element method and fatigue programs can be effective tools to eliminate the production problems and reduce costs related to fatigue of the needle material.

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