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SELECTION OF THE OPTIMAL PAPER-FORMING SIEVE OBTAINED BY THE PLASMA WELDING

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Abstract. The paper-forming sieve is the most important part of the paper production machine. Reliability of the machine as a whole depends on the sieve's quality. An analysis of the two constructions of the paper forming sieves, which were obtained by the plasma welding of the sieve's wires, is presented in this paper. The mechanical characteristics of the two sieves, made of wires of diameters 0.15 mm and 0.20 mm, were tested, namely the tensile strength and elongation. The tests have shown that the sieve made of the wire of the smaller diameter has the better mechanical properties. This sieve is also better from the aspect of the water removal in the press section of the paper machine.

Keywords: paper-forming, steel sieve, plasma welding, tensile strength, elongation

1. INTRODUCTION

Paper is a material with a complex content; it consists of cellulose fibers with addition of glues, fillers and eventually color (pigment). The process of forming the paper starts with fibers being distributed on the sieve, one next to the other, with simultaneous water flowing through the sieve thus forming the paper strip (Duraković et al., 2018).

Paper forming consists of removing water from a dilute suspension of fiber and other materials by filtration, what leaves the solids in form of a coherent sheet. Water removal from fiber webs on the paper machine is a hydro-mechanical process, accomplished by a sequence of mechanisms, like the wire clothes, felt or screen for drainage etc., (www.pulppapermill.com). Paper manufacturing involves the sequential removal of water from the pulp by means of gravity, vacuum dewatering, mechanical press and thermal drying in a paper machine. The percentage moisture content in the incoming pulp slurry is about 99.5%. It is decreased to 4–8% in the final product, (Sjöstrand, 2017; Taban et al., 2009).

Paper is being manufactured on a paper machine. With regard to specific application and construction solutions, these machines can be very different. They are divided into

three general groups: Fourdrinier machines, twin-ply formers and multi-ply formers. The Fourdrinier machines are the most common type of the paper machines, where the stock (the pulp enriched by blenders) is drained on a moving horizontal screen, called a fabric. In the twin-wire formers, the stock is filtered between the two fabrics, while the multi-ply formers are used for paperboard manufacturing. Regardless of the type, all the machines consist of the stock distribution system, head box, forming section, press section drying section, calendaring section and reel.
The flat wire machine (Fourdrinier) is a paper machine with a horizontal, moving, fine mesh, woven wire cloth or plastic fabric on which the pulp slurry is deposited, forming the web. The wire forms a continuous belt that picks up fiber at the breast roll from the head box, runs over the table rolls, foils, suction boxes and then over a couch roll, where the web of fibers leaves the Fourdrinier table, Figure 1, (Drummond et al., 2010). The wire then continues around the couch roll, under the machine, to the breast roll where more fibers are received. The position and tension of the wire are controlled by special rolls.
The paper-manufacturing machine, in general, consists of three sections – the wire section (where the paper enters with humidity of 99 %), the press section (entering paper humidity is 80 %) and the drying section (paper enters with 50 % humidity and leaves the machine with 5 %), (Drummond et al., 2010). The paper humidity is usually given as the (mass of water/mass of cellulose) ratio. The rate and separation effectiveness of the water removal from paper fiber webs is significant for efficiency of the paper forming process, (Leimu, 2018; Botonjić, 2017).

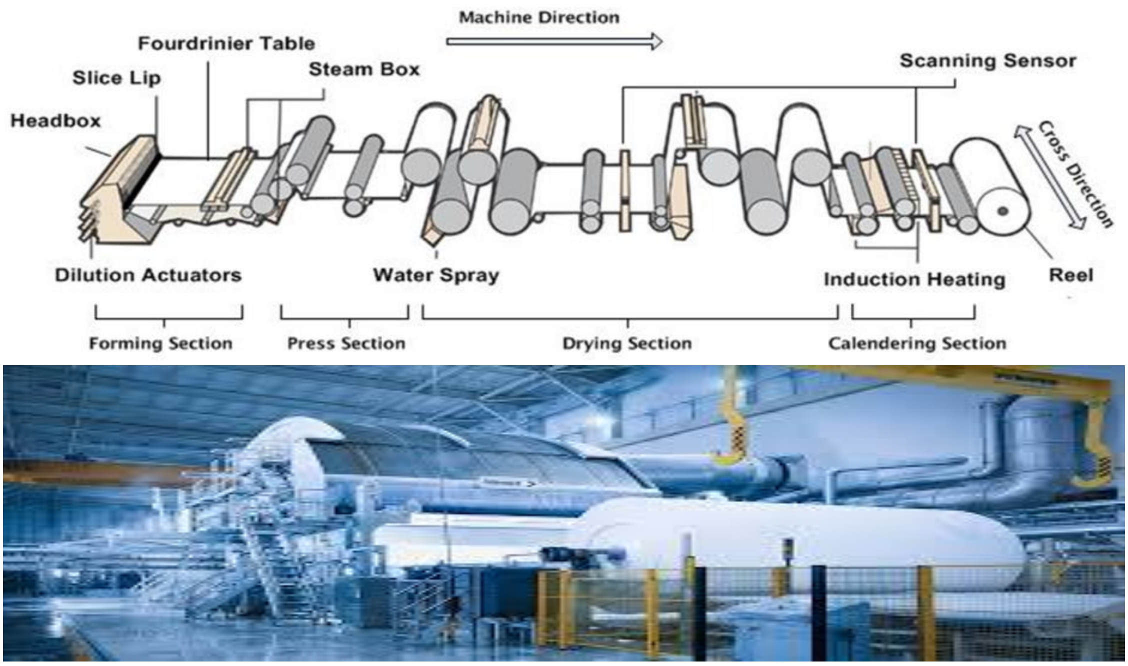

Fig. 1. The paper-manufacturing machine: The Fourdrinier machine schematics (above) and appearance of the machine (below) (Chu et al., 2011).

Numerous attempts were reported for optimization of different parts of the paper-manufacturing machine and the paper-forming process itself, like paper-converting, mathematical models of the nip, the felts and the press-section, etc. The research, results of which are presented in this paper, was focused on optimization of the forming fabric, the steel sieve. The two constructions of the steel sieve, obtained by the plasma welding, were tested and their results were compared to each other, to establish which of them is the better one, i.e. optimal for this particular paper-forming process.

2. THE STEEL SIEVE

The paper forming process is being influenced by a large number of factors: concentration of the paper mass, type of the sieve, temperature, pressure intensity beneath the sieve, paper-machine operation rate, pH value of the environment, chemical additives, etc. In the paper-forming process, besides the pulp, the most important role is played by the sieve. It consists of the endless metal or synthetic woven. It moves over the two main cylinders, the breast roll and the suction roll. Besides those two, there are other cylinders, as well, the guide roll, the tension roll, the table rolls, the wire return roll, Figure 2, (Bajpai, 2018).

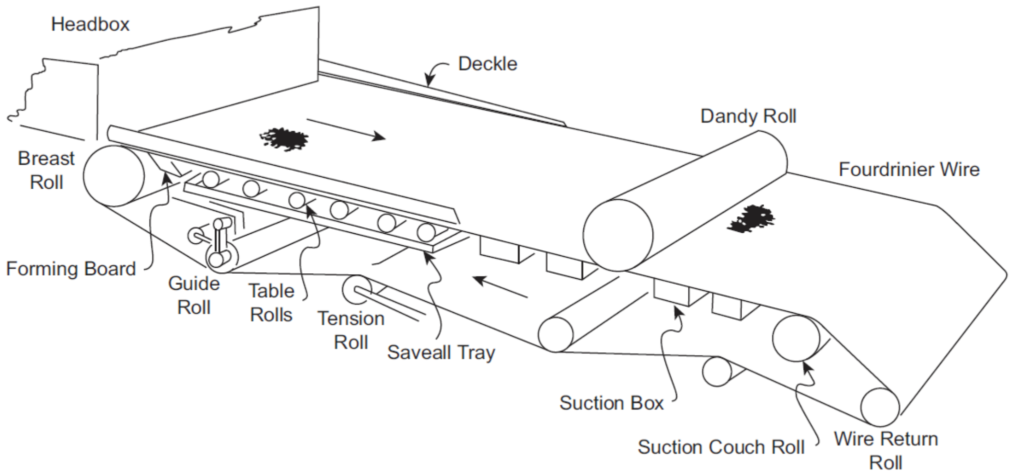

Fig. 2. A Fourdrinier wet end

The sieve (also called the forming fabric), is a continuous loop or belt of finely woven screen made from steel wire or plastics; of various openings' sizes (10-25 per cm). A coarser wire allows for faster water drainage but produces the coarser paper and vice versa. Before the 1960 ties, wires were almost exclusively made of metals but now they are practically all made of plastics, like polyester. The plastic sieves last much longer than the steel ones; they possess the good corrosion resistance, as well. However, the negative properties of the plastic sieves include bigger stretching (elongation) and the poor resistance to abrasive materials.

The sieve (usually referred to as the forming media) in the paper machine has three functions: transporting the fiber, permitting the draining of a sheet and transmitting the power, (Drummond et al., 2010).

The sieve represents the basic working conveyer on which the paper sheet is formed; it must possess the high filtrating property, while simultaneously it must prevent the loss of fillers and fibers. The higher quality the sieve, the higher is the quality of the paper (Bojić et al., 2019). The sieve's fineness is expressed by the sieve's number, which refers to number of longitudinal wires per centimeter. The sieves with longitudinal wires in pairs are used for the fine paper sheets manufacturing. Such a construction increases smoothness of the paper's surface. The sieve's dimensions must be bigger than dimensions of the uncircumcised paper's width.

The most known and applied are the diagonal steel sieves obtained by the plasma welding. Plasma arc welding is a welding method where the plasma jet is used as a source of intense heat to melt the material to be welded. It belongs to the same group of welding processes like the conventional gas shielded arc welding processes like the gas tungsten arc (GTA), gas metal arc (GMA), or the high-power-density welding processes like the electron beam (EB) and laser beam (LB) welding, (Martikainen and Moisio, 2009). In the keyhole-processing mode, the arc power density is higher than with the GTA, GMA and plasma arc processes. The welding parameters must be carefully balanced to maintain the stability of the keyhole and the weld pool, since instabilities can result in various weld discontinuities.

During the arc welding, plasma is produced by an electric arc, which passes through a gas separating two electrodes. The arc heat ionizes the gas producing a plasma stream; arc temperatures are within the range between 15000 and 27000 K.

The plasma welding without the filler metal with very small thermal influence on the base metal represents the best technological method for sieve joining, used in the paper manufacturing, (Bojic et al., 2012). In Figure 3 are shown joints of the steel sieves executed by the silver soldering and plasma arc welding. The difference in the joint's quality is obvious. This type of joining produces the welded joint thickness equal to thickness of the steel sieve's wire, with the exceptionally smooth and even weld's surface, which is necessary for the high quality joint of the sieve. The plasma welding is the stable welding process and it does not leave trace of wires of the paper's surface what is extremely important in the paper forming.

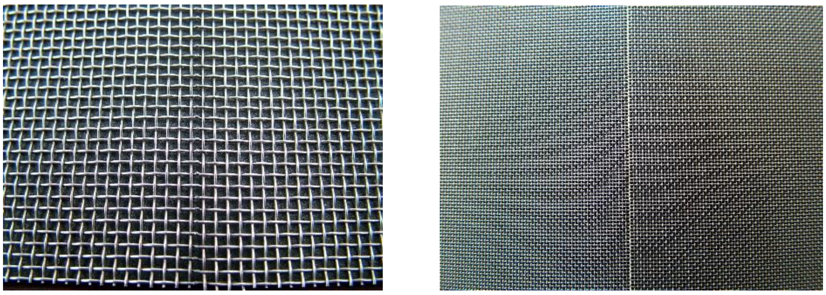

Fig. 3. Plasma welded sieve joint (left) and Silver soldering sieve joint (right).

3. Experimental investigation

Experimental investigation consisted of the tensile test where the wire's elongation, the maximal force and force at wire's break were recorded, as well as the maximal strain and strain at break. The test was performed on the universal ZWICK ROELL Z010 testing machine in the laboratory for mechanical testing of the Factory of Sieves and Bearings "FASIL" A.D., Arilje, Serbia, Figure 4, (Bojic et al., 2012). One of the pneumatic jaws for tightening the sample was tied to the fixed and the other to the mobile part of the testing machine. The pneumatic jaws were tightened in such a way to occupy automatically a position where the longitudinal axis of the wire matches the loads direction that goes through the axis of jaws when changing the load. The maximal distance between the pneumatic jaws was 590 mm. The wire was well fixed in order to avoid its drawing out of the jaws due to slipping during the tightening. Mechanism was without inertia with regulated testing rate and it recorded the unit elongation with accuracy of at least 1%. The main testing parameters were: the maximal force 10 000 N, the grip to grip distance 350 mm, test rate 10 mm/min, the force shutdown threshold 60 % and the upper limit force for the sieve testing 1800 N.

The steel sieve was joined by the plasma welding. Two types of sieves were tested with ID number N_o30 and wire diameters of 0.15 and 0.20 mm. Sieves of this type are used for producing the paper of weight of 30 to 200 gr/m^2. The sample with wire of 15 mm diameter had dimensions, cross-section width and length a_0 = 0.34 mm and b_0 = 28 mm, respectively and length L_0 = 300 mm, while the sample with 0.20 mm wire had dimensions a_0 = 0.51 mm, b_0 = 28 mm and L_0 = 300 mm. In Figure 5 is shown appearance of the input data screen of the testing equipment.

Fig. 4. Experimental testing machine ZWICK ROELL Z010

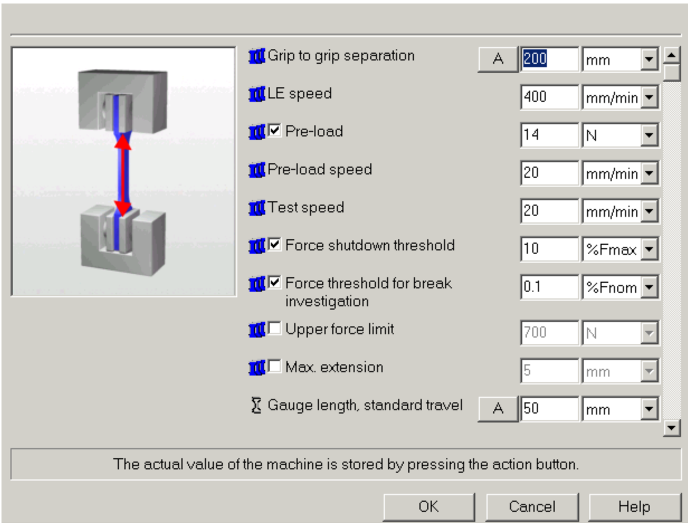

Fig. 5. The testing machine input data.

4. Results and discussion

The test results are presented in form of the force strain diagrams, Figures 6 and 7 and in tables 1 to 4. Tables 1 and 3 are showing results of the investigated mechanical characteristics of the two sieves. The following notation is used in these two tables: F_{max} is the maximal force, F_{break} is the force at the sample's break, ε_{break} is strain at break and ε_{Fmax} is the strain at the maximal applied force. Tables 2 and 4 are presenting the statistical results of those tests. In these two tables, the notation is as follows: $\bar{x}$ is the mean value of the particular tested variable, while σ is the standard deviation and v is the variance coefficient (in %).

Table 1
Mechanical characteristics of the plasma welded joint of the wire of 0.15 mm diameter

Variable	a_0	b_0	L_0	$F_{max.}$	F_{break}	ε_{break}	ε_{Fmax}
Sample #	mm	mm	mm	N	N	%	%
1	0.34	28	300.08	944.04	928.54	10.54	10.53
2	0.34	28	300.11	1052.55	1011.78	14.42	14.34
3	0.34	28	300.18	1081.13	1081.13	15.59	15.59
4	0.34	28	300.25	1051.44	1051.41	14.89	14.89

Table 2
Statistics of the mechanical characteristics' tests of the plasma welded joint of the wire of 0.15 mm diameter

Variable	a_0	b_0	L_0	$F_{max.}$	F_{break}	ε_{break}	ε_{Fmax}
	Mm	mm	mm	N	N	%	%
$\bar{x}$	0.34	28	300.15	1032.29	1018.21	13.86	13.84
σ	0.000	0.000	0.07	60.42	66.19	2.26	2.26
v	0.00	0.00	0.04	5.85	6.50	16.33	16.36

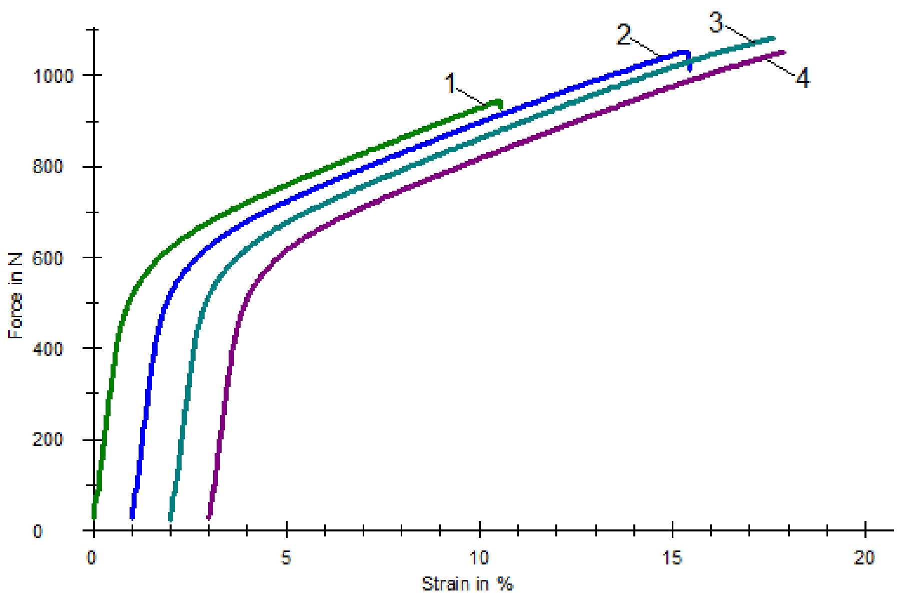

Fig. 6. The force-strain diagram for the sieve made of wires of 0.15 mm diameter

Comparison of diagrams in Figures 6 and 7, namely values in Tables 1 and 3 shows that the force at break of the plasma-welded joints of the two steel sieves has lower values for samples with the larger wire diameter (0.20 mm). This indicates that these welded joints will break earlier than joints for the sieve with wire diameter 0.15 mm. The elongation at maximum force is also larger for the second series of samples.

Table 3
Mechanical characteristics of the plasma welded joint of the wire of 0.20 mm diameter

Variable	a_0	b_0	L_0	$F_{max.}$	F_{break}	ε_{break}	ε_{Fmax}
Sample #	mm	mm	mm	N	N	%	%
1	0.51	28	300.15	764.79	745.82	4.76	4.71
2	0.51	28	300.19	642.30	628.32	11.65	11.60
3	0.51	28	300.18	712.20	703.28	13.92	13.91

Table 4
Statistics of the mechanical characteristics' tests of the plasma welded joint of the wire of 0.20 mm diameter

Variable	a_0	b_0	L_0	$F_{max.}$	F_{break}	ε_{break}	ε_{Fmax}
	mm	mm	mm	N	N	%	%
$\bar{x}$	0.51	31.33	300.17	706.43	692.47	10.11	10.07
σ	0.000	5.859	0.02	61.45	59.49	4.77	4.79
v	0.00	18.70	0.01	8.70	8.59	47.19	47.54

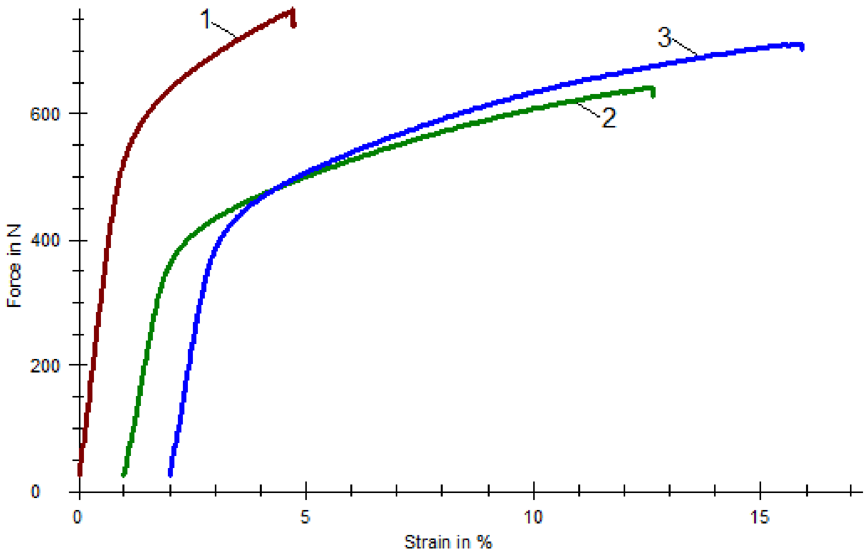

Fig. 7. The force-strain diagram for the sieve made of wires of 0.20 mm diameter

5. Conclusions

This paper presents results of experimental tests executed on the plasma-welded joints of the two types of steel sieves used in the paper-forming process. The welded joint of the sieve with wire of the 0.20 mm diameter is of the worse quality with respect to the welded joint of the sieve with wire of the 0.15 mm dimeter. The former sieves can sustain lesser force (the force at break is 47 % smaller), which means that they would break before the latter ones. That would cause stopping of the paper-forming process due to necessary replacement of the sieve, which, in turn, causes the downtime costs in the manufacturing process. Another reason, why the construction of the sieve with smaller wire diameter is better, is that with wire of the bigger diameter the opening between the individual wires are smaller, which can cause jamming of the fibers and retaining of the pulp. Due to the pressure of the water from the pulp, the fibers are clogging the openings on the sieve, which leads to increase of the loading on it and causes the break of the plasma-welded joints.

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