Evaluation of the mechanical properties and failure mechanism of fibres formed in municipal wastewater systems

D Micota¹, S V Galatanu¹*, L Marsavina¹ and S Muntean¹,²

¹ Politehnica University of Timisoara, 1 Mihai Viteazu Blvd.,
300222, Timisoara, Romania
² Romanian Academy – Timisoara Branch, 24 Mihai Viteazul Blvd.,
300223, Timisoara, Romania

*Corresponding author: sergiu.galatanu@upt.ro

Abstract. The rainwater axial pumps are specially designed to operate in municipal wastewater systems. The fibres and wastes are discharged during storms with this type of pumps. Several problems have occurred in service due to the fibres clogging up the impeller. Therefore, the chemical compositions of the waste, microscopic analyses, tensile and shearing tests were performed on the debris collected into the rainwater pumps in order to determine it structure and mechanical properties. The failure mechanism of fibres was also determined. It was confirmed that the tensile and shear strength of wet fibres are higher than the dry ones. Also, the value obtained by shearing tests is higher than the values obtained by tensile tests for both wet and dry fibres. This approach represents a useful engineering tool for determination of mechanical properties and failure mechanism of fibres formed in the municipal wastewater systems that lead to clogging up the impeller.

1. Introduction

The wastewater treatment plant (WTP) of Timisoara was rehabilitated during 2009 – 2011 and it was commissioned in March 2011. The Timisoara’s WTP was designed to provide services for 440000 inhabitants. Today, more than 350000 inhabitants (97% from the total number of Timisoara’s inhabitants), are connected to the city’s sewerage system. The annual average volume of the wastewater treated in Timisoara’s WTP is more than 42.1 million m³. Up to 10% of this volume is rainwater. The maximum capacity of Timisoara’s WTP is 3 m³/s. The additional flow over the maximum capacity of the WTP from rains and storms is discharged in Bega River using seven axial rainwater pumps with maximum flow rate of 4 m³/s on each pump. Two rainwater pumps have had catastrophic failure that took them out of operation for several weeks, Figure 1.

Nowadays, the wastewaters contain a higher amount of synthetic cloth and artificial fibres such as tissues, wipes, and dishcloths. The most common solid parts found in municipal wastewater are organic and often consist of long and stringy shapes, such as fibres, Figure 2. Also, the infiltration sand is trained by the wastewater stream [1].

The major problem is the catastrophic failure of the rainwater pump impeller. The failure is caused by clogging up the pump impeller, Figure 3. For this type of axial rainwater pumps, the gap between impeller blades and casing is clogged leading to the radial deflection of the impeller. The impeller deflection is followed by mechanical friction between it blades and casing producing the catastrophic failure of the rainwater pumps.
Isono et al. [2] have conducted an experimental study on the pump clogging phenomena showing that the length of the string significantly affects the probability of passing. The reason for clogging is versatile [3-5]. Any object that fits into the municipal wastewater pipe systems can be involved. Gerlach et al. [6] have shown that the hydraulic performance of the wastewater pumping station discovered that clogging not only leads to pump failures but also reduces the attainable flow rates greatly. Additionally, clogging results is found in a loss of energy-efficiency.

**Figure 1.** Fibres accumulation on the blades of the impeller of the rainwater pumps. One impeller blade is missing due to the catastrophic failure.

**Figure 2.** Typical rag ball removed from the impellers of the rainwater pumps.

**Figure 3.** Fibres accumulation in the blade regions of pluvial pumps: stay vanes (left) and impeller (right).

The purpose of this paper is to determine the properties of the fibres accumulated in the rainwater pumps that lead to clogging up the impeller. The paper includes laboratory investigation and test results concerning wastes collected from the municipal wastewater systems. This part is divided into three subchapters. The first two subchapters present the procedures and results for determining the chemical composition and microscopic examination of the waste and next subchapter present the tensile and shear tests performed on the fibres and the results of investigations. The main conclusions are summarized in the last section.
2. Laboratory investigations and test results
The chemical compositions, microscopic analyses, tensile and shear tests were performed in order to determine the mechanical properties of the fibres collected into the rainwater pumps in order to investigate the causes that lead to catastrophic failure of the rainwater pumps. The mechanism of breaking the fibres collected from the rainwater pumps is proposed based on the results obtained from the microscopic analysis of the breaking zones. It was noted that our results are supported by Hearles et al. [7].

2.1. Chemical compositions
The chemical composition of the municipal wastes from the rainwater pump was determined in two steps. The initial weight of investigated municipal waste was 16.5 g. First, the waste was immersed into 100 ml distilled water during 24 hours to determine the amount of water-soluble substances. Next, the waste was sunk into 100 ml petroleum ether during 24 hours to determine fat-soluble substances. At the end of the procedure, it was recorded that the municipal waste did not change its appearance.

The results obtained for the chemical composition of the municipal waste is presented in Figure 4.

![Figure 4. Chemical composition of the waste.](image)

Following the procedure, it was noticed that 17% of the initial mass of the waste is composed by dyes and amines dissolved into the distilled water, 16% are fats selected into petroleum ether and 67% are fibres.

2.2. Microscopic examination
The microscopic examination was performed with the optical microscope. The microscopic analysis was considered in the breaking zones of the fibres (wastes) on transversal and longitudinal directions, respectively. The breaking mechanism of the fibres includes that the interaction between fibrils will be very weak and they will be separated independently. After breaking of all fibrils the two ends are separated, followed by the break. Figure 5 shows the schematic representation of independent fibrillary break.

![Figure 5. Schematic representation of independent fibrillary break.](image)

(a) Structure of separate fibrils, only weakly linked, (b) Under sufficient tension, fibrils begin to break, (c) Finally all fibrils have broken and the ends can separate, (d) Two broken ends, (e) Possible collapse to tapering ends, [7].
Figure 6 shows a microscopic examination of the waste, in which the fibres breaking mechanism can be seen. The fibres are formed from assembly of crystalline fibrils. Fibrils break down progressively after which the remaining fibres cannot longer supports the load, and the failure occurs in the direction of the main stresses at 45 degrees. The fibres breaking area are presented in Figure 7 while a detail of the fats from the fibres is evidenced in Figure 8.

The microscopic examinations performed on the fibres in transversal direction, respectively in longitudinal direction indicate the structure of a composite material consisting from fibres, sand, stones and fats, Figure 9.

Figure 6. Microscopic analysis of the waste: fibres breaking mechanism for shear tests

Figure 7. Breaking area of the fibres

Figure 8. Detail of the fats from the fibres

Figure 9. Microscopic analysis of the waste material: transversal section (left) and longitudinal section (right).
2.3. Tensile and shear tests

Tensile and shear tests have been conducted in the Strength of Materials Laboratory from Politehnica University Timisoara. The tests were performed on a Zwick Proline Z005 universal test machine with a maximum force of 5 kN at the ambient temperature. Figure 10 shows the universal test machine and the grip for the tensile tests is detailed in Figure 11.

The tests were performed using a control displacement with a loading speed of 10 mm/min both for dry and wet fibres. The wet fibres were kept in water during 24 hours before to start the test. Several cross sections were measured along to the fibre in order to estimate it average diameter.

![Figure 10. Zwick Proline Z005 universal test machine](image1)

The shear tests were performed on a special device designed and built to determine the shearing strength of the metal bars. Figure 12 presents the shearing device installed on the universal testing machine.

A blank test was only performed on the shearing device itself to determine the characteristic force-displacement curve of the device. The shearing force of the fibre is determined by eliminating the drive force of the shearing device from the shearing force recorded at the fibres breakage. This force value was used to determine the shearing strength of the fibres.

The specimens were cut from the same cords that were also tested for tensile strength.

![Figure 11. Grip detail for tensile test](image2)

![Figure 12. Grip detail for shearing device](image3)

The force – displacement curves obtained on several specimens of the dry/wet fibres under the tensile tests are given in Figure 13. One can observe a large spreading of the result due to the anisotropic structure of the fibres and the variation of the number of fibres in the tested specimens. Also, one can distinguish a different behaviour of the dry and wet fibres under the tensile tests because the water acts like a plasticizer and it strongly modifies the mobility of the amorphous part of macromolecules and shifts, similar as temperature [8 – 9]. The moisture drastically change the properties of fibres. Figure 14 presents the force – displacement curves obtained on several specimens of the dry/wet fibres under
shearing tests. The effect of the spring from the shear fixture (long initial linear part) was subtracted in order to calculate maximum shear force. The force – displacement curves have a linear-elastic area up to maximum force after which some of them are breaking immediately and others have a progressive degradation mechanism.

![Force displacement curves](image1)

**Figure 13.** Force – displacement curves obtained on several specimens of fibres under the tensile tests: dry fibres (left) and wet fibres (right)

![Force displacement curves](image2)

**Figure 14.** Force – displacement curves obtained on several specimens of fibres under the shearing tests: dry fibres (left) and wet fibres (right)

In Figure 15 are presented several broken fibres specimens following the shearing tests. The fibres specimens tested have different thicknesses and structures because of them are formed as irregular strings during storms discharge. A total of 40 specimens were used for the tests: 10 specimens for tensile tests for dry fibres, 10 specimens for tensile tests for wet fibres, 10 specimens for shearing tests for dry fibres and 10 specimens for shearing tests for wet fibres.

![Broken specimens](image3)

**Figure 15.** Three fibres specimens broken under shearing tests.
The average values for tensile and shearing strengths of the dry and wet fibres are presented in Figure 16. One can observe that the average value of the tensile strength for the dry fibres is 5.73 MPa and 27.01 MPa for the wet fibres, respectively. It is noted that the tensile strength of the wet fibres is 4.7 times higher than that of the dry fibres. Niconov et al. [9] have arrived at the same conclusion testing climbing cords because moisture has an effect analogous to the temperature effect on the cords and fibres.

The average value for shearing strength of the dry fibres is 16.55 MPa, respectively 55.13 MPa for wet fibres. It can be seen that the average shearing strength is 2.9 times higher than the tensile strength for the dry fibres. The difference between shearing and tensile strengths is given by fact that in case of the tensile tests breakage is achieved progressively by tearing, the fibres being non-homogeneous in their length while in the case of shearing tests all area of fibres is loaded directly. Also, the composite structure of the waste/specimens (fibres, sand, and so on) plays an important role during the shearing tests in order to define it strength. The average shearing strength is 3.3 times higher for the wet fibres than the dry ones.

![Figure 16. Average of tensile and shearing strength for the dry and wet fibres.](image)

A correlation between the maximum force and the fibres cross section area is obtained for tensile/shear data in Figure 17 with lower coefficients ($R^2=0.320/0.581$ for tensile/shear tests) due to non-homogeneity (different composition and structure) of the tested wet fibres. These correlations will be used to estimate the force required to break by stretching or shearing the fibres which clog the gap between impeller blade and casing.

![Figure 17. The experimental data (*) and it linear regression function (—) for the wet fibres under tension (left) and shearing (right) tests.](image)
3. Conclusion
The paper presents our experimental investigations performed on waste collected from the municipal wastewater system. The chemical composition and microscopic analysis of the waste material is performed. As a result, the waste composition determined in our case is: 17% dyes and amines, 16% fats and 67% fibres. The mechanical properties of the dry and wet fibres under tensile and shear conditions are obtained. The breaking mechanism and tensile and shearing strength of the fibres was identified. It was noted that the results for tensile strength of wet fibres is higher with 21.2% than the results of dry fibres. The results for shearing strength of the wet fibres are higher with 28.2% than the results of dry fibres. The results show that the shearing strength of the fibres is higher with 51% than the tensile strength. The results lead to the conclusion that wet fibres require a higher force for breaking both in tensile and shearing. This approach represents a useful engineering tool for determination of mechanical properties and failure mechanism of fibres formed in the municipal wastewater systems that lead to clogging up the impeller.

4. References
[1] Wang Z, Du X, Yang Y and Ye X 2012 Surface clogging process modeling of suspended solids during urban stormwater aquifer recharge *Journal of Environmental Sciences* **24** (8): 1418–1424
[2] Isono M, Nohmi M, Uchida1 H, Kawai M, Kudo H, Kawahara T, Miyagawa K and Saito S 2014 An experimental study on pump clogging, IOP Conf. Ser.: Earth Environ. Sci. **22** 012009:1-11
[3] Höchel K, Thamsen P U and Rauwald H 2013 Analysing sewage handling problems, *World Pumps* 6:30-33
[4] Moore G 2011 Intelligent control of sewage pumps *World Pumps* 6:26-33
[5] *** 2012 Clogging: not just throughlet size *World Pumps* 9:34-38
[6] Gerlach S, Ugarelli R and Thamsen P U 2016 Case Study on the Functional Performance of a large Wastewater Pumping Station *International Symposium on Transport Phenomena and Dynamics of Rotating Machinery* Hawaii, Honolulu April 10-15
[7] Hearles J W S, Lomas B and Cooke W D, *Atlas of fibre fracture and damage to textile*, Secound Edition, Department of Textiles, University of Manchester Institute of Science and Technology
[8] Lawrence S St, Willett J L and Carriere C J 2001 Effect of moisture on the tensile properties of poly(hydroxy ester ether) *Polymer* **42** 5643 – 5650
[9] Nikonov A, Saprunov I, Zupančič B and Emri I 2011 Influence of moisture on functional properties of climbing ropes *International Journal of Impact Engineering* **38** (11):900-909.

Acknowledgment
The authors are gratefully for the financial support of Bridge Grant TANAGRA/63BG2016 project code PN-III-P2-2.1-BG-2016-0082 entitled “Transfer of knowledge to the economic operator” - financed by the Romanian Government and also for the support of Municipal Water Company AQUATIM SA Timișoara.