DEVELOPMENT AND EVALUATION OF PRECISION WOVEN WIRE CLOTH FOR SIEVES AND FILTERS, AN ULTRAFINE WOVEN WIRE CLOTH WITH A SQUARE OPENING SIZE OF 13 μm AND MESH COUNTS OF 977 WIRES PER LINEAR INCH

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ABSTRACT

With narrow square opening size distribution woven wire cloth guarantees an excellent separation and classifying accuracy. Stainless-steel is a common material for woven wire cloth, and due to its thermal and mechanical strength,and its high chemical stability, it can be used in demanding conditions, such as at high temperatures and high pressures. As an ultrafine woven wire cloth manufacturer, Asada Mesh has been able to successfully produce a precision woven stainless-steel wire cloth with a square opening size of 13 μm (0.0005 inch) and 977 wires per linear inch (product name SV13/13, hereafter called #977). Techniques were also developed for weaving #977 in a width of 1220 mm. This paper gives an overview of the evaluation of #977's square opening sizes.

So far, ASTM E-11 designates nominal opening sizes of industrial woven wire cloth for sieving as fine as 20 μm (0.0008 inch) with 635 wires per linear inch. Our product range includes a woven SUS wire cloth with a square opening size of less than 20 μm with openings size of 16 μm (0.0006 inch) and 795 wires per linear inch (product name Sieve SV16/16, hereafter called #795). However, no industrial standards for measuring the square opening size of #977 and #795 have been defined. In this study, the square opening size of #977 was measured using an image analyzer, PoreSizer™ (Whitehouse Scientific Ltd). The square opening size of #977 ranged from 11.0-15.7 μm, with a mode diameter of 13.0 μm and σ = 0.667. These results confirm that #977 is a high-precision woven wire cloth.

Wet filtration tests of non-spherical silica were conducted to investigate the separation performance of #977. The particle size distribution of silica feed and filtrate was determined by laser diffraction (Mastersizer 3000, Malvern Panalytical). The particle size distribution of the samples ranged from 0.525-123 μm. After filtration, the size distribution of particles sieved through #977 achieved D(90): 13.0 μm and D(97): 17.6 μm. Considering that the samples are non-spherical, #977 was shown to classify particles of equivalent square opening size with high accuracy.

The filtration efficiency, pressure drop and tensile strength of #977 are evaluated too.

KEYWORDS: Mesh, Square opening, Pressure drop, Simulation, Classification

1. Introduction

With narrow square opening size, woven wire cloth guarantees an excellent separation and classifying accuracy. Stainless-steel is a common material for woven wire cloth for its mechanical strength as well as high thermal and chemical stability. Such properties allows for implementation in demanding conditions, such as operation in high temperatures and high pressures. Therefore, woven stainless-steel wire cloth allows for a wide range of applications as sieves and filters. ASADA MESH CO., LTD. is the world leading ultrafine woven wire cloth manufacturer and the first in the world to successfully produce a precision woven stainless-steel wire cloth with a square opening size of 13 µm (0.0005 inch) at 977 wires per linear inch (product name Sieve SV13/13, hereafter called #977, **Fig. 1**). Furthermore, a novel technique was developed for weaving #977 at a width of 1220 mm.
Until now, ISO3310-1 designates nominal opening sizes of industrial woven wire cloth for sieving down to 20 µm (0.0008 inch) at 635 wires per linear inch [1]. Our product portfolio now includes woven stainless-steel wire cloths with a square opening size of less than 20 µm. In addition to #977 a square opening size of 16 µm (0.0006 inch) and 795 wires per linear inch is currently produced (product name Sieve SV16/16 [2], hereafter called #795). However, industrial standards for measuring the square opening size of #977 and #795 is yet to be defined.
Considering the current limitation, this publication evaluates the performance between #977 and Microsieve (1000 Line/inch) from a variety of perspectives. Both #977 and Microsieve has identical square opening sizes of 13 µm (**Fig. 2**). Microsieve is manufactured by electroforming with square opening sizes of 13 µm, a mesh number of 1000, and a thickness of 8 µm. On the other hand, #977 is 29 µm thick and has a mesh number of 977.
The evaluations consisted of square opening size measurements, tensile strength tests, pressure drop measurements, sieve evaluation in wet filtration tests, calculation of pressure drop and sieve efficiency using simulation software.

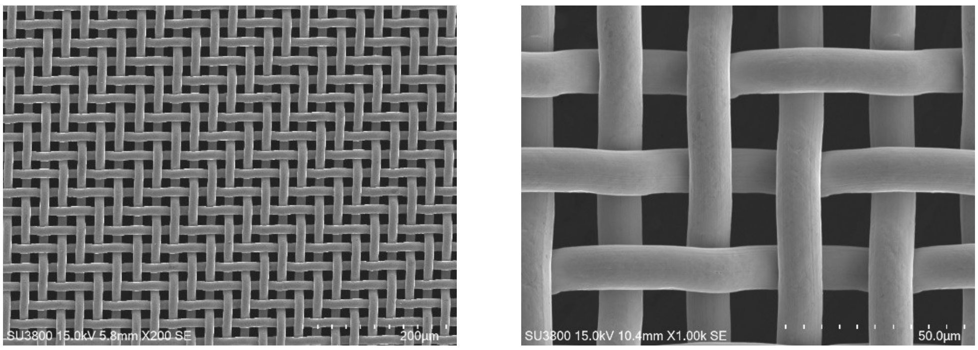

Fig. 1　SEM image of #977 (left : 200x, right : 1000x)

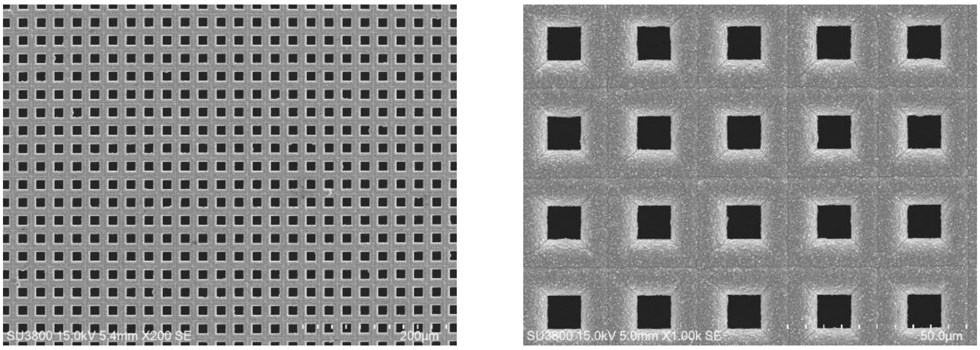

Fig. 2　SEM image of Microsieve (left : 200x, right : 1000x)

2. Basic evaluation of mesh

This section provides details of the square opening size measurements and tensile strength tests.

2.1. Measurement of square opening size

2.1.1. Measurement method

#977 and Microsieve were measured at 3 positions each. 500 openings were measured per position. The measurement positions of #977 were set at the left, center and right ends of the 1220 mm weaving width. For the measurement of the Microsieve, three pieces cut out to 47 mm in diameter were used to measure the center of the Microsieve. The square opening size of samples were measured using an image analyzer, PoreSizer™ (Whitehouse Scientific Ltd, **Fig. 3**). The PoreSizer™ can simultaneously measure all openings in the field of view of the microscope at once, as shown in Fig. 3. The ISO standard defines as measuring one opening, followed by the upper right-hand side of the opening, which is repeated for a given number of openings. In this measurement, the ISO standard was used as a basis. After measuring an opening in the field of view of the microscope, we moved the field of view to the upper right corner of the microscope so that the opening to be measured would not be covered, and measured the next opening, which was repeated until 500 openings were reached.

2.1.2. Results and Discussion

The square opening size measurement results of #977 and Microsieve are shown in **Fig. 4**. The width of the square opening size distribution, the mean of the opening, σ, and the number of meshes, respectively, are shown in **Table 1**. Although the mesh count of #977 varied between 966 to 990, square opening sizes was within design tolerance. The distribution of square opening size fell within the 11.0-15.7 μm range, indicating that #977 was woven with high precision.

The average square opening size of the Microsieve was 11.4 μm for a nominally 13 μm opening. The number of meshes was in line with the design values, the square opening size distribution width was very narrower than #977, and the variation in openings was small.

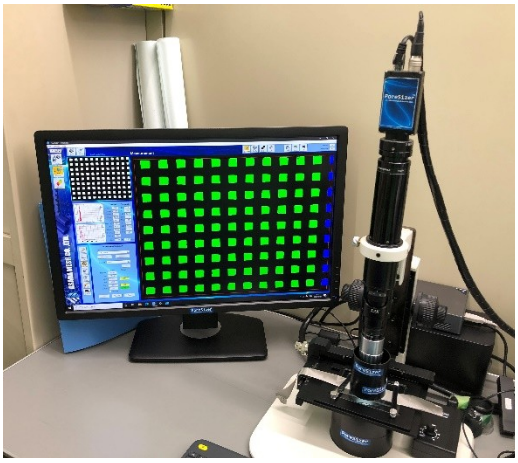

Fig. 3 PoreSizer™

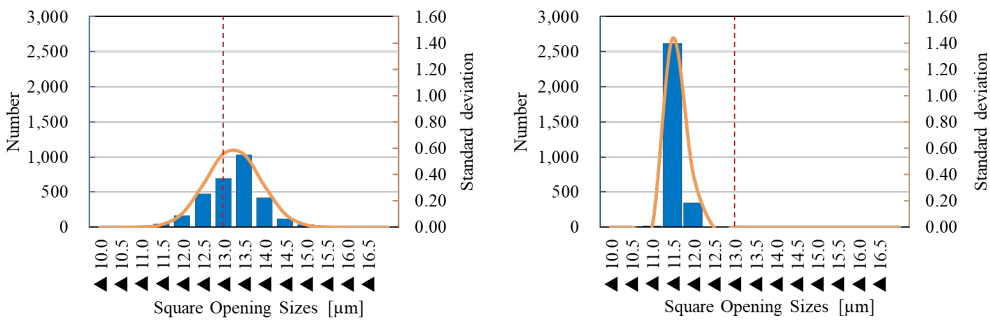

Fig. 4 The square opening size distribution of #977 (left) and Microsieve (right)

Table 1 Results of square opening size measurement

	Average [μm]	Distribution [μm]	σ	Mesh count
#977	13.0	11.0 – 15.7	0.667	966 - 990
Microsieve	11.4	9.94 – 11.9	0.180	1000 - 1001

2.2. Tensile strength test

2.2.1. Measurement method

Three pieces of #977 and Microsieve samples were cut out to 25 mm x 200 mm were prepared for tensile testing. #977 has a weave direction, so three samples were prepared in both warp direction and weft direction, respectively. The measurement was performed using the tensile tester AUTOGRAPH AG-X Plus 5 kN (SHIMADZU CORPORATION) as shown in **Fig. 5**. The test method is in accordance with JIS L 1096 [3]. In the test, the samples were clamped as shown in **Fig. 6**. The bottom clamp is fixed and the top clamp was pulled upwards to measure the test force until the sample rupture. The distance between the clamps was set to 100 mm and the rise speed of the clamps was set to 100 mm/min. The test force corresponding to the strain of the sample was evaluated.

Fig. 5 Photograph of AUTOGRAPH AG-X Plus 5 kN

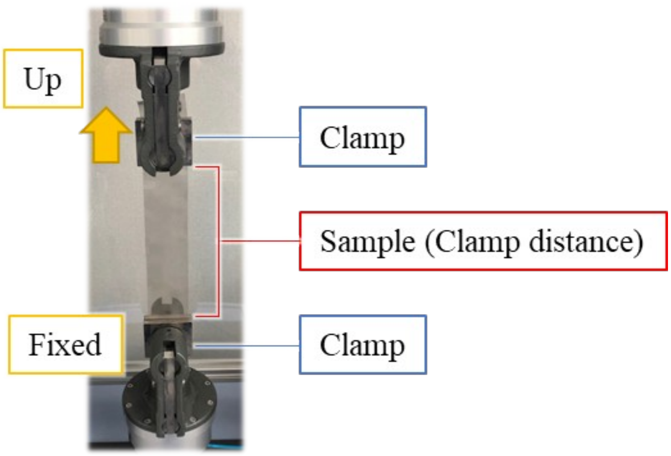

Fig. 6 Photograph of mounted filter specimen

2.2.2. Results and Discussion

Fig. 7 compares the tensile strength of #977 and Microsieve. The graph shows the second highest rupture strength among the three measurements. To deformation rate was used to evaluate the deformation of the sample in relation to the test force. **Table 2** shows the results of the deformation rates. The deformation rates were calculated by the following procedure.

1. In the graph in Fig. 7, the slope between the two measurement points was calculated, respectively.
2. As the values were not stable for some time after the start of the measurement, these values were removed. The number of samples removed was one third of the number of measurements points on each sample.
3. The maximum slope value among the remaining measurements was taken as the deformation rate.

The strain of the Microsieves was low, but the deformation rate was similar to Weft of #977. The deformation rate for #977 were different for Warp and Weft. Also, #977 was difficult to rupture because it was stretched against the pulling force.

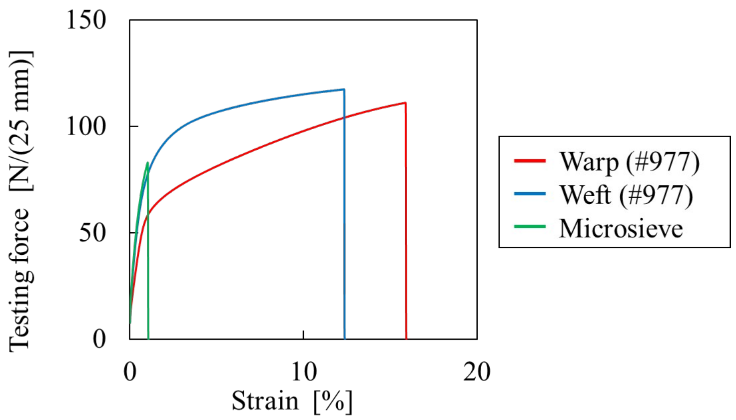

Fig. 7 Comparison of #977 and Microsieve tensile strength test results

Table 2 The deformation rate of #977 and Microsieve

Sample	#977		Microsieve
	Warp	Weft	
Deformation rate [N/25 mm]	68.6	114.9	112.4

3. Experiments

This section investigates the pressure drop of #977 and Microsieve. Furthermore, the performance and efficiency of the sieve in wet filtration. As shown in **Fig. 8**, the Microsieves have different structures on the matrix surface (hereafter called Microsieve-A) and the electroformed surface (hereafter called Microsieve-B), so each was investigated.

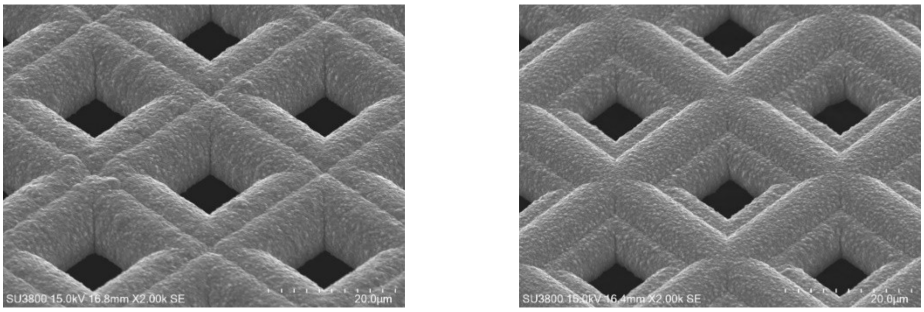

Fig. 8 SEM image of Microsieve at 2000x (left : matrix surface (Microsieve-A), right : electroformed surface (Microsieve-B))

3.1. Measurement of pressure drop

3.1.1. Measurement method

The experimental setup is shown in **Fig. 9**. As shown in **Fig. 10**, the sample was glued to a ring with an inner diameter of 25 mm and placed in the pipe (Fig. 9 A) . In order to measure the pressure drop, ion-exchanged water flowed through the equipment and pressure sensors (Pressure Sensor PSE563-02, SMC Corporation) (Fig. 9 B1, B2) were installed before and after the filter sample. The flow rate was determined in advance by gravimetric method for the pressure to flow rate (Fig. 9 C). Measurements were made during increasing flow velocity in steps and then decreasing steps, taking hysteresis into account. The relationship between pressure drop and flow rate was evaluated. Three samples of Microsieve-A, B and #977 were prepared respectively.

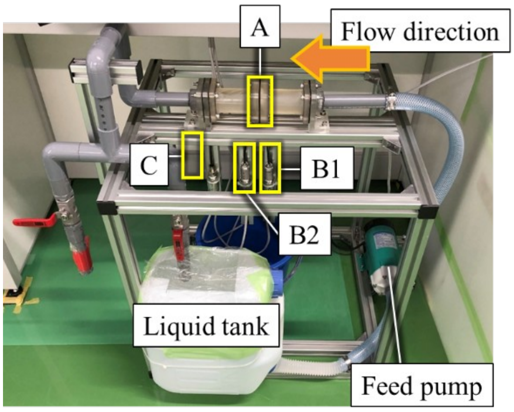

Fig. 9 Photograph of pressure drop measuring equipment

Fig. 10 Photograph of mounted #077 sample

3.1.2. Results and Discussion

Fig. 11 shows the results of the pressure drop averaged for the flow rate. Three samples of #977 showed a similar trend. The same trend was also observed between samples of Microsieves A and B. Pressure drop is similar between all three materials at low flow rates of ~0.3. As the flow rate increases, the pressure drop of #977 ~12kPa at ~1.2 m/s whilst Microsieve A and B have a pressure drop of ~18kPa at ~0.98m/s and ~17kPa at 1.0m/s.

Microsieve-A and B showed slight differences in the measured values due to the variation of the opening. There was no effect of the difference in the structure of the Microsieves.

With a thickness of 29 µm for #977 and 8 µm for the Microsieve, #977 is 3.6 times thicker. On the other hand, the average square opening size is 13.0 µm for #977 and 11.8 µm for the Microsieve. From the above, the reason for the high pressure drop of the Microsieve could simply be due to the narrower opening. Another possibility is that the pressure drop of #977 may have been lower due to the unique structure of the woven wire cloth. The effect of the square opening size on the pressure drop is discussed in the next section.

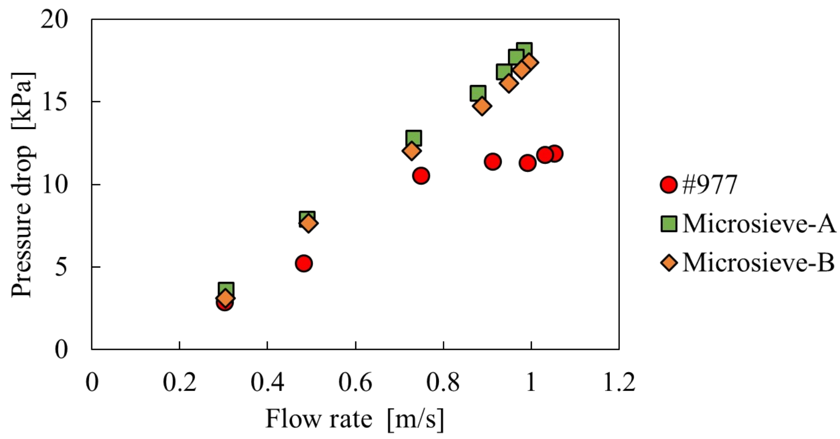

Fig. 11 Results of pressure drop measurement

3.2. Particle size distribution measurement in wet filtration

3.2.1. Test method

The test equipment for wet filtration is shown in **Fig. 12**. The sample powder was JIS Test Powders 1 and Class 2 (The Association of Powder Process Industry and Engineering, JAPAN, **Fig. 13**), both non-spherical silica powders. A suspension was prepared by dispersing 5.000 g of sample in 50 mL of ion-exchanged water and dispersing it using a glass rod. Samples cut to 47 mm in diameter were fixed on Sterifil (Merck KGaA) and the suspension was poured into Sterifil while suctioning with a vacuum pump (Rocker 300C, Rocker Scientific Co., Ltd.). During the pouring process, care was taken to ensure that the suspension did not flow directly into the sample. The remaining powder in Sterifil was rinsed and flushed with 45 mL of additional ion-exchanged water. The vacuum pump was aspirated at 80 kPa and the suspension was completely flushed and then suctioned for 5 minutes.

The particle size distribution of silica feed and filtrate was determined by laser diffraction (Mastersizer 3000E, Malvern Panalytical, **Fig. 14**). The tests were conducted under three setup, #977 and Microsieve-A and B, respectively, with the 977 being tested three times per condition and the Microsieves being tested once per condition. After completing one test, #977 was cleaned for 10 minutes at a frequency of 39 kHz and power of 100 W using an ultrasonic cleaning (UT-104, SHARP).

The absorbance of the suspension under the sieve (860 nm) was measured using a visible spectrophotometer (ASV11D, AS ONE CORPORATION). At 860 nm, the turbidity of the suspension can be determined without being affected by color [4]. Three sheets of #977 and Microsieve-A were each prepared and measured once per sheet. One sheet of Microsieve-B was prepared and the measurements were taken three times. Microsieve-B experiments were followed by immersion in ion exchange water for 3 min, followed by ultrasonic cleaning at 40 W power for 3 min.

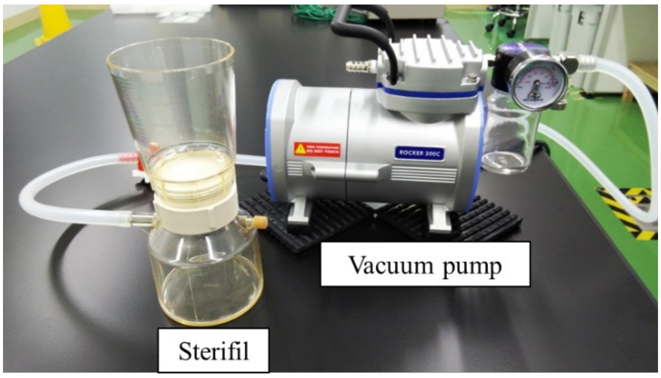

Fig. 12 Photograph of wet filtration testing equipment

Fig. 13 SEM image of sample powder (800x)

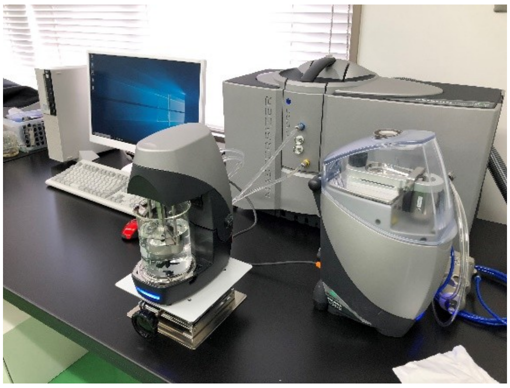

Fig. 14 Photograph of Mastersizer 3000E

3.2.2. Results and Discussion

The results of the particle size distribution under the sieve are shown in **Fig. 15** and **Table 3**. D(90) of filtrate was 12.7 μm for #977, 9.49 μm for Microsieve-A and 9.94 μm for Microsieve-B. The square opening size of #977 and Microsieve is 13 μm and 11.4 μm, respectively, which indicates that the particles passed through sample according to the square opening size. Microsieve-A and B have a D(90) slightly smaller than the opening, but they were measured under the same conditions as #977, which may not be sufficient. There was no significant difference between the results of Microsieve-A and B.

Table 4 shows the results of the absorbance measurement at 860 nm of the filtrate suspension. Although there was a large variation in the absorbance of #977, it was higher than that of Microsieve-A and B. Due to the relatively close particle size distribution of the filtrate, it is likely that more particles passed through #977 than Microsieve. It is difficult to evaluate by weight and other factors because the number of particles passed through the actual experiment is very small. The detailed sieve efficiency is discussed in the next section using simulations.

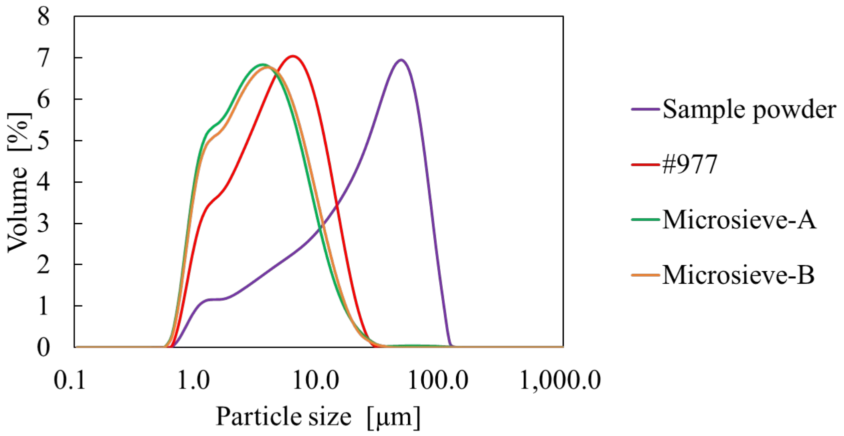

Fig. 15 Measurement results of the size distribution of filtrate sieved particles (average)

Table 3 Measurement results of the size distribution of filtrate sieved particles

		D(90) [µm]	D(97) [µm]
#977	①	13.3	17.8
		12.5	16.8
		12.3	16.8
	②	12.2	16.6
		13.0	17.7
		13.2	18.1
	③	12.8	17.2
		12.6	17.1
		12.6	17.3
#977 Average		**12.7**	**17.3**
Microseive-A	A-①	10.2	15.1
	A-②	9.05	13.5
	A-③	9.23	13.7
Microseive-A Average		**9.49**	**14.1**
Microseive-B	B-①	9.51	13.0
	B-②	10.8	16.4
	B-③	9.52	14.0
Microseive-B Average		**9.94**	**14.47**

Table 4 Absorbance measurement results of suspension filtrate sieved

		Absorbance [-]
#977	④	0.231
	⑤	0.424
	⑥	0.598
#977 Average		**0.418**
Microseive-A	A-④	0.208
	A-⑤	0.272
	A-⑥	0.184
Microseive-A Average		**0.221**
Microseive-B	B-④	0.160
		0.212
		0.312
Microseive-B Average		**0.228**

4. Simulation Compatibility

In the previous section, the pressure drop and the particle size distribution after wet filtration were determined experimentally. In this section, numerical simulation is used to investigate how these characteristics. GeoDict (Math 2 Market GmbH) was used as the simulation software. As shown in Fig. 8, the structure of the Microsieve is different on the matrix surface (Microsieve A) and the electroformed surface (Microsieve B), so an investigation was carried out on each variant.

In preliminary preparation, the virtual structures of #977 and Microsieve were created using GeoDict. The structure of #977 has a wire diameter of 13 µm, square opening size of 13 µm and thickness of 29 µm (**Fig. 16** left). As the Microsieves have a different structure to #977, a different structure was created. The Microsieves were constructed with a 13 µm diameter, 13 µm opening, and 8 µm thickness (Fig. 16 right). The Microsieve can be selected Microsieve-A or B if the structure is flipped. Simulations are performed using the above #977, Microsieve-A and B.

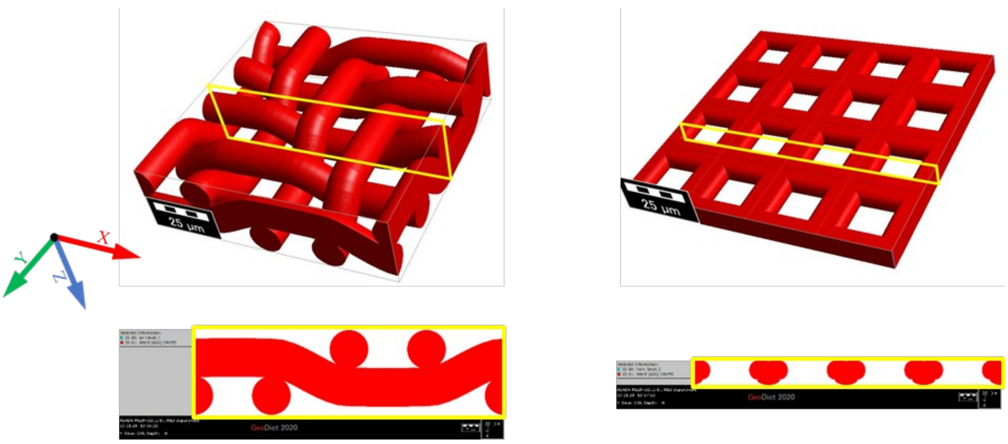

Fig. 16 Structures used in the simulation (left : #977, right : Microsieve-A)

4.1. Pressure drop

4.1.1. Simulation conditions

Using FlowDict, a solver in GeoDict, the pressure drop before and after the sample was calculated for any given flow rate. The flow rate was set at 0.2, 0.4, 0.6, 0.8 and 1.0 m/s. The sample was simulated under three conditions, #977, Microsieve-A and B. A total of 15 conditions were simulated.

4.1.2. Results and Discussion

The pressure drop values obtained from the simulations at each flow rate are shown in **Table 5** and **Fig. 17**. The pressure drop of #977 was shown to be lower even when the opening and wire diameter of #977 and Microsieve were the same. **Figs. 18 and 19** show the flow fields of #977 and Microsieve-A, respectively. #977 was found to have a lower pressure drop due to the linear formation of the flow by the weaving structure.

Table 5 Simulation results of pressure drop

		Flow rate [m/s]				
		0.2	0.4	0.6	0.8	1.0
Pressure drop [kPa]	# 977	1.271	2.888	4.923	7.349	10.17
	Microseive-A	1.528	3.863	7.068	11.17	15.86
	Microseive-B	1.515	3.875	7.086	11.14	15.90

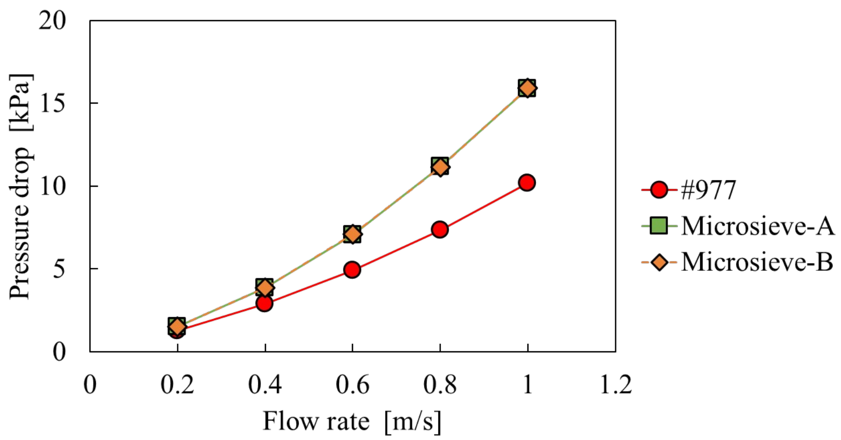

Fig. 17 Simulation results of pressure drop

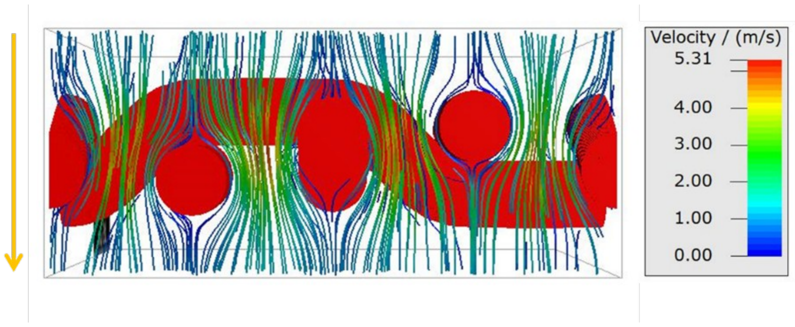

Fig. 18　#977's flow field

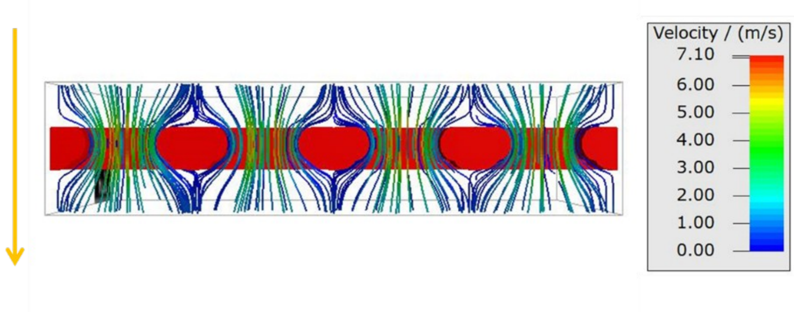

Fig. 19　Microsieve-A’s flow field

4.2. Wet filtration

4.2.1. Simulation conditions

Calculation was performed using FilterDict, a solver in GeoDict. Non-spherical silica was modelled based on materials used in section 3. In this simulation, spherical particles were selected to have the same density as silica. The particle size distribution of the sample powder was limited to fine particles in the range of 0.670 µm to 26.7 µm, eliminating coarser particles. Because of the limitations of the simulation software, coarse particles have a negative impact on the calculation. It was also simulated under an air atmosphere. Three samples, #977, Microsieve-A and B, were simulated under the same conditions. For all particles, the number of particles that passed through was evaluated.

4.2.2. Results and Discussion

The results of the simulation are shown in **Table 6** and **Fig. 20**. Fig. 20 shows the sample and particles at the end of the simulation. The filtration efficiency was determined by the following equation.

$$\text{Filtration efficiency [\%]} = \frac{\text{Filtrate [m}^3\text{]}}{\text{Feed [m}^3\text{]}} \times 100$$

The filtration efficiency of #977 is higher than the Microsieve. There was no significant difference in efficiency between Microsieve-A and B. The higher filtration efficiency of #977 was a result of the linear formation of the flow by the weaving structure (Figs. 18 and 19), making the particles less likely to collide with the mesh.

Table 6 Simulation results of particles

Sample	#977	Microsieve	
		A	B
Filtration efficiency [%]	44.6	32.6	34.4

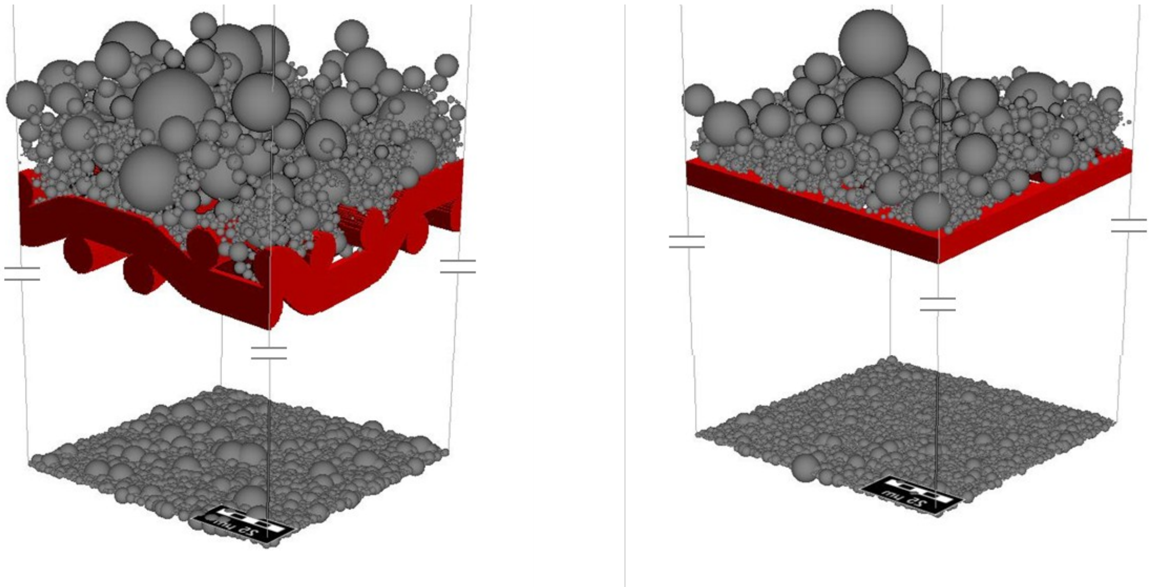

Fig. 20 The sample after the simulation (left : #977, right : Microsieve)

5. Conclusion

In this study, the newly developed #977 were evaluated from a variety of perspectives.

In section 2, the square opening size and tensile strength were measured. The square opening size of #977 ranged from 11.0-15.7 μm, with a mode diameter of 13.0 μm and $\sigma = 0.667$. These results confirm that #977 is a high-precision woven wire cloth. In addition, #977 was shown to have high rupture strength because of its stretching against pulling forces.

In section 3, the pressure drop and wet filtration were evaluated. Trend of the pressure drop increased with the increase in the flow rate. #977 achieved a low pressure drop compared to the Microsieve. Wet filtration was found to be able to collect particles equivalent to the square opening size and was found to be repeatable with ultrasonic cleaning.

In section 4, the experiments conducted in section 3 were evaluated by simulation. Numerical model predicts the pressure drop shows that #977 shows a lower pressure drop compared to a Microsieve with equivalent wire diameter and opening. This is in line with results observed in section 3. #977 was found to have a lower pressure drop due to the linear formation of the flow by the weaving structure. Wet filtration simulations were also evaluated for filtration efficiency, which was not evaluated in experimental section. In addition to pressure drop, filtration efficiency was found to be higher. Based on the pressure drop and wet filtration results, #977 was considered to be better because the flow field is linearly formed by the weaving structure.

#977 is a woven stainless-steel wire cloth with a 13 μm wire diameter and a 13 μm opening and could be a valuable addition to sieves and filters industry in the future.

References

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