Experimental data for physical characteristics, fiber compositions, and tensile properties of nonwoven wipes and toilet papers

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ABSTRACT

This article presents experimental data for physical characteristics, fiber compositions, and tensile properties of non-flushable wipes, flushable wipes, and toilet papers. Samples included 42 flushable wipes, 16 non-flushable wipes, and 11 toilet papers that were collected from around the world by considering product diversity in their retail regions (e.g., north america, and europe), manufacturers (e.g., global, and regional), and function (e.g., baby, toddler, patient, adult, and feminine wipes). The data were generated in accordance with relevant standard methods of International Organization for Standardization (ISO). The data are provided here in full (not hosted by any public repository) in association with the research article: “Physical characteristics, fiber compositions, and tensile properties of nonwoven wipes and toilet papers in relevance to what is flushable” [1]. Readers are referred to the research article for discussions and interpretations of the data presented in this document.

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1. Data

1.1. Physical characteristics

Tables 1 and 2 present physical characteristics of non-flushable wipes in their moist-as-received states, and in their dry states, respectively. Table 3 through 6 present the same information for flushable wipe samples. Essential statistics of the data are available in the last two rows of relevant tables. Interpretations and discussions of the data are provided in our associated article [1]. For physical characteristics of toilet papers, we refer the readers to our previous publication [2].

Our data are composed of raw, and analyzed quantities as follows: 1- A physical property, such as sheet mass, was quantified by measuring sheet masses of several specimens of a sample; then, the arithmetic average of these measured values was reported as the sheet mass of that sample. 2- A physical property, such as surface area, was computed as the product of length and width of a sheet. For clarity, we use an example case (sample no.1 in Table 1) to demonstrate step-by-step how we quantified the data for that sample.

For sheet mass measurements, we removed three separate sheets from top, middle, and bottom parts of a sample’s package. Then, we measured mass of each sheet gravimetrically, estimated arithmetic average of the three measurements, and reported this value as the sheet mass of that sample. We...
Table 1
Physical characteristics of non-flushable moist wipe samples from around the world. Physical characteristics were quantified by using moist sheets in their as-received state (e.g., as in their retail package). Sample IDs indicate NF: Non-flushable wipe, and SN: Sample Number.

| No. | I.D.      | Sheet Mass (g/sheet) | Surface Area (Length x Width) (cm²) | Sheet Thickness (µm) | Sheet Volume (cm³) | Basis Weight (g/m²) | Specific Volume (dm³/kg) |
|-----|-----------|----------------------|-------------------------------------|----------------------|-------------------|---------------------|--------------------------|
| 1   | NF-SN-1   | 6.0                  | 340                                 | 336                  | 11.4              | 176                 | 1.9                      |
| 2   | NF-SN-2   | 6.5                  | 302                                 | 342                  | 10.3              | 215                 | 1.6                      |
| 3   | NF-SN-3   | 7.2                  | 349                                 | 321                  | 11.2              | 207                 | 1.5                      |
| 4   | NF-SN-4   | 5.1                  | 371                                 | 330                  | 12.2              | 137                 | 2.2                      |
| 5   | NF-SN-5   | 5.2                  | 312                                 | 312                  | 9.8               | 166                 | 1.8                      |
| 6   | NF-SN-6   | 4.1                  | 334                                 | 300                  | 10.4              | 124                 | 2.4                      |
| 7   | NF-SN-7   | 3.6                  | 328                                 | 315                  | 9.5               | 108                 | 2.9                      |
| 8   | NF-SN-8   | 3.2                  | 332                                 | 285                  | 9.9               | 95                  | 2.8                      |
| 9   | NF-SN-9   | 3.9                  | 294                                 | 335                  | 9.8               | 134                 | 2.5                      |
| 10  | NF-SN-10  | 3.6                  | 213                                 | 330                  | 7.0               | 168                 | 1.9                      |
| 11  | NF-SN-11  | 6.9                  | 353                                 | 339                  | 12.0              | 196                 | 1.9                      |
| 12  | NF-SN-12  | 6.5                  | 362                                 | 376                  | 13.6              | 191                 | 2.0                      |
| 13  | NF-SN-13  | 4.8                  | 282                                 | 236                  | 6.7               | 232                 | 1.4                      |
| 14  | NF-SN-14  | 2.6                  | 231                                 | 306                  | 7.0               | 205                 | 3.4                      |
| 15  | NF-SN-15  | 4.5                  | 274                                 | 213                  | 5.8               | 94                  | 1.4                      |
| 16  | NF-SN-16  | 4.9                  | 296                                 | 335                  | 10.0              | 152                 | 2.2                      |
|     | Average   | 4.9                  | 311                                 | 313                  | 9.8               | 163                 | 2.1                      |
|     | Range     | 2.6–7.2              | 213–371                             | 213–376              | 5.8–13.6          | 94–232              | 1.4–3.4                  |

* “s” means standard deviation, and “ε” means standard error.

Table 2
Physical characteristics of dry non-flushable wipe samples from around the world. Physical characteristics were quantified by using sheets that were dried at 40 °C for 24 h. Sample IDs indicate NF: Non-flushable wipe, and SN: Sample Number.

| No. | I.D.      | Sheet Mass (g/sheet) | Surface Area (Length x Width) (cm²) | Sheet Thickness (µm) | Sheet Volume (cm³) | Basis Weight (g/m²) | Specific Volume (dm³/kg) | Moisture (%) |
|-----|-----------|----------------------|-------------------------------------|----------------------|-------------------|---------------------|--------------------------|--------------|
| 1   | NF-SN-1   | 1.8                  | 347                                 | 448                  | 15.5              | 52                  | 8.6                      | 70           |
| 2   | NF-SN-2   | 1.5                  | 281                                 | 531                  | 14.9              | 55                  | 9.7                      | 76           |
| 3   | NF-SN-3   | 1.9                  | 324                                 | 351                  | 11.4              | 59                  | 6.0                      | 74           |
| 4   | NF-SN-4   | 1.4                  | 300                                 | 336                  | 10.1              | 48                  | 7.1                      | 72           |
| 5   | NF-SN-5   | 1.4                  | 291                                 | 419                  | 12.2              | 47                  | 8.8                      | 73           |
| 6   | NF-SN-6   | 1.4                  | 323                                 | 283                  | 9.1               | 44                  | 6.4                      | 66           |
| 7   | NF-SN-7   | 1.3                  | 319                                 | 434                  | 13.9              | 40                  | 10.8                     | 64           |
| 8   | NF-SN-8   | 1.2                  | 315                                 | 493                  | 15.5              | 38                  | 12.8                     | 62           |
| 9   | NF-SN-9   | 1.2                  | 283                                 | 312                  | 8.9               | 43                  | 7.3                      | 69           |
| 10  | NF-SN-10  | 1.2                  | 203                                 | 288                  | 5.8               | 58                  | 5.0                      | 67           |
| 11  | NF-SN-11  | 1.9                  | 320                                 | 416                  | 13.3              | 59                  | 7.1                      | 71           |
| 12  | NF-SN-12  | 1.8                  | 333                                 | 386                  | 12.8              | 55                  | 7.0                      | 72           |
| 13  | NF-SN-13  | 1.4                  | 266                                 | 352                  | 9.4               | 51                  | 6.9                      | 72           |
| 14  | NF-SN-14  | 1.0                  | 273                                 | 390                  | 10.6              | 46                  | 8.4                      | 61           |
| 15  | NF-SN-15  | 1.6                  | 280                                 | 178                  | 4.9               | 52                  | 3.4                      | 58           |
| 16  | NF-SN-16  | 1.2                  | 296                                 | 323                  | 9.6               | 77                  | 4.2                      | 71           |
|     | Average   | 1.5                  | 297                                 | 371                  | 11.1              | 52                  | 7.5                      | 69           |
|     | Range     | 1.0–1.9              | 203–347                             | 178–531              | 5.0–15.5          | 38–77               | 3.4–12.8                 | 58–76        |

* “s” means standard deviation, and “ε” means standard error.
Table 3
Physical characteristics of flushable moist wipe samples from North America. Physical characteristics were quantified by using moist sheets in their as-received state (e.g., as in their retail package). Sample IDs indicate NA: North America (flushable), and SN: Sample Number.

| No. | I.D.      | Sheet Mass (g/sheet) | Surface Area (Length x Width) (cm²) | Sheet Thickness (μm) | Sheet Volume (cm³) | Basis Weight (g/m²) | Specific Volume (dm³/kg) |
|-----|-----------|----------------------|-------------------------------------|----------------------|---------------------|----------------------|--------------------------|
| 1   | NA-SN-1   | 3.8                  | 180                                 | 320                  | 5.7                 | 210                  | 1.5                      |
| 2   | NA-SN-2   | 5.5                  | 250                                 | 327                  | 8.2                 | 220                  | 1.5                      |
| 3   | NA-SN-3   | 4.2                  | 208                                 | 311                  | 6.5                 | 202                  | 1.5                      |
| 4   | NA-SN-4   | 4.9                  | 237                                 | 305                  | 7.2                 | 206                  | 1.5                      |
| 5   | NA-SN-5   | 5.2                  | 237                                 | 343                  | 8.2                 | 218                  | 1.6                      |
| 6   | NA-SN-6   | 4.6                  | 236                                 | 316                  | 7.5                 | 194                  | 1.6                      |
| 7   | NA-SN-7   | 4.0                  | 237                                 | 276                  | 6.5                 | 170                  | 1.6                      |
| 8   | NA-SN-8   | 5.0                  | 241                                 | 297                  | 7.2                 | 209                  | 1.4                      |
| 9   | NA-SN-9   | 5.8                  | 274                                 | 227                  | 6.2                 | 212                  | 1.1                      |
| 10  | NA-SN-10  | 6.3                  | 203                                 | 413                  | 8.4                 | 311                  | 1.3                      |
| 11  | NA-SN-11  | 4.5                  | 261                                 | 391                  | 10.2                | 171                  | 2.3                      |
| 12  | NA-SN-12  | 4.3                  | 213                                 | 319                  | 6.8                 | 203                  | 1.6                      |
| 13  | NA-SN-13  | 5.0                  | 232                                 | 412                  | 9.5                 | 216                  | 1.9                      |
| 14  | NA-SN-14  | 4.1                  | 250                                 | 381                  | 9.6                 | 164                  | 2.3                      |
| 15  | NA-SN-15  | 3.7                  | 201                                 | 373                  | 7.5                 | 186                  | 2.0                      |
| 16  | NA-SN-16  | 3.8                  | 269                                 | 343                  | 9.2                 | 140                  | 2.5                      |
|     | **Average** | **4.7**          | **233**                              | **335**              | **7.8**             | **202**             | **1.7**                 |
|     | **Range** | **3.7–6.3**        | **180–274**                          | **227–413**          | **5.7–10.2**        | **140–311**          | **1.1–2.5**             |

* "s" means standard deviation, and "ε" means standard error.

Table 4
Physical characteristics of dry flushable wipe samples from North America. Physical characteristics were quantified by using sheets that were dried at 40 °C for 24 h. Sample IDs indicate NA: North America (flushable), and SN: Sample Number.

| No. | I.D.      | Sheet Mass (g/sheet) | Surface Area (Length x Width) (cm²) | Sheet Thickness (μm) | Sheet Volume (cm³) | Basis Weight (g/m²) | Specific Volume (dm³/kg) | Moisture (%) |
|-----|-----------|----------------------|-------------------------------------|----------------------|---------------------|----------------------|--------------------------|--------------|
| 1   | NA-SN-1   | 1.1                  | 170                                 | 327                  | 5.6                 | 62                   | 5.3                      | 72           |
| 2   | NA-SN-2   | 1.5                  | 237                                 | 263                  | 6.2                 | 64                   | 4.1                      | 73           |
| 3   | NA-SN-3   | 1.5                  | 190                                 | 572                  | 10.9                | 80                   | 7.2                      | 64           |
| 4   | NA-SN-4   | 1.8                  | 222                                 | 631                  | 14.0                | 81                   | 7.8                      | 63           |
| 5   | NA-SN-5   | 1.7                  | 220                                 | 565                  | 12.4                | 79                   | 7.2                      | 66           |
| 6   | NA-SN-6   | 1.6                  | 222                                 | 449                  | 9.9                 | 74                   | 6.1                      | 64           |
| 7   | NA-SN-7   | 1.3                  | 219                                 | 309                  | 6.8                 | 59                   | 5.2                      | 68           |
| 8   | NA-SN-8   | 1.6                  | 237                                 | 264                  | 6.2                 | 67                   | 3.9                      | 68           |
| 9   | NA-SN-9   | 1.8                  | 260                                 | 317                  | 8.3                 | 67                   | 4.7                      | 70           |
| 10  | NA-SN-10  | 1.4                  | 197                                 | 407                  | 8.0                 | 70                   | 5.8                      | 78           |
| 11  | NA-SN-11  | 1.4                  | 255                                 | 296                  | 7.6                 | 53                   | 5.6                      | 70           |
| 12  | NA-SN-12  | 1.6                  | 203                                 | 437                  | 8.9                 | 79                   | 5.5                      | 63           |
| 13  | NA-SN-13  | 1.4                  | 226                                 | 359                  | 8.1                 | 61                   | 5.9                      | 72           |
| 14  | NA-SN-14  | 1.4                  | 250                                 | 330                  | 8.2                 | 55                   | 6.0                      | 61           |
| 15  | NA-SN-15  | 1.2                  | 200                                 | 314                  | 6.3                 | 58                   | 5.4                      | 58           |
| 16  | NA-SN-16  | 1.3                  | 261                                 | 420                  | 11.0                | 51                   | 8.2                      | 71           |
|     | **Average** | **1.5**          | **223**                              | **391**              | **8.6**             | **66**               | **5.9**                  | **68**       |
|     | **Range** | **1.1–1.8**       | **170–261**                          | **263–631**          | **5.6–14**          | **51–81**            | **3.9–8.2**              | **58–78**    |

* "s" means standard deviation, and "ε" means standard error.
The physical characteristics of flushable wipe samples from European and Far Eastern countries were quantified by using moist sheets in their as-received state (e.g., in their retail package). Sample IDs indicate EU (flushable), FE: Far East (flushable), and SN: Sample Number.

| No. | I.D.     | Sheet Mass (g/sheet) | Surface Area (Length x Width) (cm²) | Sheet Thickness (µm) | Sheet Volume (cm³) | Basis Weight (g/m²) | Specific Volume (dm³/kg) |
|-----|----------|----------------------|------------------------------------|----------------------|-------------------|---------------------|--------------------------|
| 1   | EU-SN-1  | 4.3                  | 255                                | 239                  | 6.1               | 168                 | 1.4                      |
| 2   | EU-SN-2  | 4.3                  | 267                                | 303                  | 8.1               | 160                 | 1.9                      |
| 3   | EU-SN-3  | 5.1                  | 228                                | 292                  | 6.7               | 222                 | 1.3                      |
| 4   | EU-SN-4  | 4.6                  | 236                                | 387                  | 9.1               | 196                 | 2.0                      |
| 5   | EU-SN-5  | 4.7                  | 235                                | 397                  | 9.3               | 201                 | 2.0                      |
| 6   | EU-SN-6  | 2.9                  | 205                                | 185                  | 3.8               | 141                 | 1.3                      |
| 7   | EU-SN-7  | 2.9                  | 244                                | 320                  | 7.8               | 117                 | 2.7                      |
| 8   | EU-SN-8  | 4.6                  | 227                                | 335                  | 7.6               | 204                 | 1.6                      |
| 9   | EU-SN-9  | 4.9                  | 252                                | 335                  | 8.4               | 195                 | 1.7                      |
| 10  | EU-SN-10 | 3.9                  | 223                                | 150                  | 3.3               | 177                 | 0.8                      |
| 11  | EU-SN-11 | 4.5                  | 200                                | 337                  | 6.7               | 227                 | 1.5                      |
| 12  | EU-SN-12 | 4.5                  | 269                                | 266                  | 7.2               | 167                 | 1.6                      |
| 13  | EU-SN-13 | 4.2                  | 264                                | 238                  | 6.3               | 159                 | 1.5                      |
| 14  | EU-SN-14 | 3.9                  | 222                                | 255                  | 5.7               | 178                 | 1.4                      |
| 15  | EU-SN-15 | 3.8                  | 213                                | 326                  | 6.9               | 177                 | 1.8                      |
| 16  | EU-SN-16 | 5.2                  | 222                                | 321                  | 7.1               | 233                 | 1.4                      |
| 17  | EU-SN-17 | 5.2                  | 222                                | 318                  | 7.1               | 234                 | 1.4                      |
| 18  | EU-SN-18 | 5.0                  | 206                                | 352                  | 7.3               | 244                 | 1.4                      |
| 19  | FE-SN-1  | 4.0                  | 306                                | 314                  | 9.6               | 127                 | 2.4                      |
| 20  | FE-SN-2  | 4.3                  | 385                                | 382                  | 14.7              | 111                 | 3.4                      |
| 21  | FE-SN-3  | 6.0                  | 338                                | 421                  | 14.6              | 177                 | 2.4                      |
| 22  | FE-SN-4  | 5.8                  | 374                                | 364                  | 15.7              | 155                 | 2.7                      |
| 23  | FE-SN-5  | 4.3                  | 270                                | 312                  | 8.4               | 159                 | 2.0                      |
| 24  | FE-SN-6  | 6.8                  | 446                                | 297                  | 12.9              | 152                 | 1.9                      |
| 25  | FE-SN-7  | 3.8                  | 366                                | 185                  | 6.6               | 103                 | 1.7                      |
| 26  | FE-SN-8  | 5.3                  | 389                                | 393                  | 9.8               | 136                 | 1.9                      |

Average: 4.6, Range: 2.9–6.8, n=20–46, s=0.9, e=0.2

*“s” means standard deviation, and “e” means standard error.

Present below the individual readings, the average sheet mass, and the reported value for sample no.1 in Table 1 as an example case.

| Sheet mass measurement-1 (g) | Sheet mass measurement-2 (g) | Sheet mass measurement-3 (g) | Arithmetic average of sheet mass measurements (g) | Reported sheet mass value (g) |
|-----------------------------|-----------------------------|-----------------------------|--------------------------------------------------|-------------------------------|
| 5.97                        | 6.04                        | 6.01                        | 6.00                                             | 6.0                           |

For length and width of a sheet, we used two separate sheets to quantify each dimension, and then, we estimated surface area as the product of length and width. For the example case (sample no.1 in Table 1), our measurements, the estimated surface areas, and the arithmetic average of surface areas were quantified as follows.
For sheet thicknesses, Fig. 1 depicts typical cross-sections of moist flushable, and moist non-flushable wipes under the light microscope. As illustrated, the cross-section of a wipe appears non-uniform with fibers in slight disarray; therefore, we took five thickness measurements as minimum, maximum, and three other representative readings along the cross-section of each sheet. The arithmetic average of the five measurements was reported as the average sheet thickness.

| No. | I.D.      | Sheet Mass (g/sheet) | Surface Area (Length x Width) (cm²) | Sheet Thickness (μm) | Sheet Volume (cm³) | Basis Weight (g/m²) | Specific Volume (dm³/kg) | Moisture (%) |
|-----|-----------|----------------------|------------------------------------|----------------------|--------------------|----------------------|--------------------------|--------------|
| 1   | EU-SN-1   | 1.4                  | 244                                | 273                  | 6.6                | 59                   | 4.6                      | 66           |
| 2   | EU-SN-2   | 1.4                  | 254                                | 311                  | 7.9                | 55                   | 5.7                      | 68           |
| 3   | EU-SN-3   | 1.3                  | 214                                | 310                  | 6.6                | 63                   | 4.9                      | 73           |
| 4   | EU-SN-4   | 1.5                  | 228                                | 287                  | 6.5                | 65                   | 4.4                      | 68           |
| 5   | EU-SN-5   | 1.5                  | 224                                | 307                  | 6.9                | 65                   | 4.7                      | 69           |
| 6   | EU-SN-6   | 1.0                  | 197                                | 246                  | 4.8                | 52                   | 4.7                      | 65           |
| 7   | EU-SN-7   | 1.1                  | 237                                | 174                  | 4.1                | 48                   | 3.7                      | 61           |
| 8   | EU-SN-8   | 1.4                  | 231                                | 298                  | 6.9                | 63                   | 4.8                      | 69           |
| 9   | EU-SN-9   | 1.6                  | 237                                | 356                  | 8.4                | 68                   | 5.3                      | 76           |
| 10  | EU-SN-10  | 1.1                  | 200                                | 221                  | 4.4                | 54                   | 4.1                      | 67           |
| 11  | EU-SN-11  | 1.3                  | 195                                | 305                  | 6.0                | 69                   | 4.5                      | 66           |
| 12  | EU-SN-12  | 1.5                  | 252                                | 351                  | 8.8                | 60                   | 5.8                      | 67           |
| 13  | EU-SN-13  | 1.5                  | 247                                | 190                  | 4.7                | 59                   | 3.2                      | 75           |
| 14  | EU-SN-14  | 1.1                  | 202                                | 352                  | 7.1                | 52                   | 6.8                      | 73           |
| 15  | EU-SN-15  | 1.1                  | 203                                | 340                  | 6.9                | 56                   | 6.0                      | 70           |
| 16  | EU-SN-16  | 1.4                  | 228                                | 310                  | 7.0                | 60                   | 5.2                      | 74           |
| 17  | EU-SN-17  | 1.4                  | 222                                | 378                  | 8.4                | 64                   | 5.9                      | 73           |
| 18  | EU-SN-18  | 1.4                  | 206                                | 363                  | 7.5                | 67                   | 5.4                      | 73           |
| 19  | FE-SN-1   | 1.2                  | 289                                | 313                  | 8.9                | 42                   | 7.4                      | 70           |
| 20  | FE-SN-2   | 1.4                  | 357                                | 294                  | 10.4               | 39                   | 7.4                      | 67           |
| 21  | FE-SN-3   | 2.3                  | 344                                | 545                  | 18.6               | 67                   | 8.0                      | 62           |
| 22  | FE-SN-4   | 2.0                  | 343                                | 532                  | 18.2               | 58                   | 9.1                      | 65           |
| 23  | FE-SN-5   | 1.2                  | 273                                | 482                  | 13.1               | 44                   | 10.9                     | 72           |
| 24  | FE-SN-6   | 2.3                  | 433                                | 510                  | 22.1               | 53                   | 9.6                      | 66           |
| 25  | FE-SN-7   | 1.6                  | 356                                | 234                  | 8.2                | 45                   | 5.1                      | 58           |
| 26  | FE-SN-8   | 2.0                  | 376                                | 531                  | 20                  | 53                   | 10.0                     | 62           |
|     | Average   | 1.5                  | 261                                | 339                  | 9.2                | 57                   | 6.0                      | 68           |
|     | Range     | 1.0–2.3              | 195–433                            | 174–545              | 4.1–22             | 39–69                | 3.2–10.9                 | 58–76        |
|     | s*        | 0.35                 |                                    |                      |                    |                      |                          |              |
|     | e*        | 0.07                 |                                    |                      |                    |                      |                          |              |

* “s” means standard deviation, and “e” means standard error.
We present below five thickness measurements and their arithmetic average that is reported as the sheet thickness of sample no.1 in Table 1.

| Thickness measurement-1 (maximum) (µm) | Thickness measurement-2 (minimum) (µm) | Thickness measurement-3 (representative) (µm) | Thickness measurement-4 (representative) (µm) | Thickness measurement-5 (representative) (µm) |
|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| 390                                    | 295                                    | 333                                    | 322                                    | 340                                    |
| Arithmetic average of five measurements (µm) | (390 + 295 + 333 + 322 + 340)/5 = 336 |
| Reported average thickness of sample no.1 (µm) | 336                                    |

Fig. 1. Pictures of cross-sections of moist flushable (panel a), and moist non-flushable wipes (panel b) under a light microscope.

Table 7
Characteristics of the two toilet paper samples used for fiber analysis in this study.

| Parameter             | European TP Sample (TP-EU-SN-1) | North American TP Sample (TP-NA-SN-5) |
|-----------------------|---------------------------------|--------------------------------------|
| Sheet mass (mg)       | 622                             | 444                                  |
| Basis weight (g/m²)   | 50                              | 41                                   |
| Sheet thickness (µm)  | 175                             | 130                                  |
| Sheet volume (cm³)    | 2.2                             | 1.4                                  |
| Specific volume (L/kg) | 3.5                             | 3.3                                  |
| Fmax (dry-state) (N)  | 5.4                             | 2.8                                  |
| Manufacturer          | Global                          | Global                               |
Table 8
Microscopic images of stained plant fibers of two independent TP samples. Fiber appearances match with physical descriptions and expected colors of plant-based fibers as indicated by each staining procedure. Sample IDs indicate TP: Toilet paper, NA: North America, EU: Europe, and SN: Sample Number.

| Sample ID  | Staining Method | Fiber Description & Expected Fiber Color | Fiber Appearance |
|------------|-----------------|----------------------------------------|------------------|
| TP-EU-SN-1 | Herzberg        | Non-uniform shape with rough side-edges and pointed-ends. Darkish-bluish violet | ![Image](image1) |
| Dupont     |                 | Non-uniform shape with rough side-edges and pointed-ends. Green & yellow | ![Image](image2) |
| TP-NA-SN-5 | Herzberg        | Non-uniform shape with rough side-edges and pointed-ends. Darkish-bluish violet | ![Image](image3) |
| Dupont     |                 | Non-uniform shape with rough side-edges and pointed-ends. Green & yellow | ![Image](image4) |
By using the measured quantities and the equations below, we estimated other physical properties including sheet volume, basis weight, and specific volume as follows

Sheet volume = surface area x sheet thickness.
Basis weight = Sheet mass/surface area.

Table 9
Microscopic images of RC fibers after staining. Fiber appearances match with physical descriptions and expected colors of RC fibers as indicated by each staining procedure. Absence of any other fiber type confirms that the wipe sample is composed of RC fibers by 100%. Sample IDs indicate FL: Flushable, NF: Non-flushable, NA: North America, and SN: Sample Number.

| Sample ID   | Staining Method | Fiber Description & Expected Fiber Color | Fiber Appearance |
|-------------|-----------------|------------------------------------------|------------------|
| NF-SN-11    | Herzberg        | Long and uniform fibers with smooth side-edges. Darkish-bluish violet | ![Image](image1.png) |
|             | Dupont          | Long and uniform fibers with smooth side-edges. Greenish-blue | ![Image](image2.png) |
| FL-EU-SN-14 | Herzberg        | Long and uniform fibers with smooth side-edges. Darkish-bluish violet | ![Image](image3.png) |
|             | Dupont          | Long and uniform fibers with smooth side-edges. Greenish-blue | ![Image](image4.png) |
Specific volume = Sheet volume/sheet mass.
Accordingly, the computed properties of sample no. 1 of Table 1 are
Sheet volume = 340 (cm²) x 336 (µm) x (1 cm/10000 µm) = 11.4 cm³,
Basis weight = 6.0 g / 340 cm² x (10000 cm² / 1 m²) = 176 g/m²,
Specific volume = 11.4 cm³ x (1 dm³ / 1000 cm³) / (6.0 g) x (1000 g / 1 kg) = 1.9 dm³/kg.

1.2. Identification of fiber types through fiber staining

Table 7 presents characteristics of two independent toilet paper (TP) samples that were selected for application of fiber staining methods. Table 8–10 present fiber compositions of representative samples. The tables include sample IDs, staining methods, expected colors of fibers, physical description of fibers, and the actual appearance of fibers under a light microscope. Specifically, Table 8 depicts plant fibers of the two independent TP samples, while Table 9 illustrates fibers of two independent wipe samples (non-flushable, and flushable) that are composed of only regenerated cellulose (RC) fibers. Physical characteristics of these samples, NF-SN-11 (non-flushable) and NA-SN-10 (flushable), are available in Tables 1 and 3 of this article, respectively. Table 10 demonstrates fibers of a flushable wipe sample that is composed of plant-based, and RC fibers. Physical characteristics of this sample, EU-SN-5, are available in Table 5 of this document.

Table 10
Microscopic images of plant-based, and RC fibers after staining. Fiber appearances match with physical descriptions and expected colors of both plant-based, and RC fibers as indicated by each staining procedure. Sample IDs indicate FL: Flushable, EU: Europe, and SN: Sample Number.

| Sample ID | Staining Method | Fiber type | Fiber Description & Expected Fiber Color | Fiber Appearance |
|-----------|----------------|------------|------------------------------------------|-----------------|
| FL-EU-SN-5 | Herzberg       | RC fiber   | Long and uniform shape with smooth side-edges. Darkish-bluish violet | ![Micr...](attachment://image.png) |
|           |                | Plant fiber| Non-uniform shape with rough side-edges and pointed-ends. Darkish-bluish violet | ![Micr...](attachment://image.png) |
| Dupont    | RC fiber       | Long and uniform fibers with smooth side-edges. Greenish-blue | ![Micr...](attachment://image.png) |
|           | Plant fiber    | Non-uniform shape with rough side-edges and pointed-ends. Green & yellow | ![Micr...](attachment://image.png) |
1.3. Tensile properties

Table 11–18 present tensile properties of non-flushable wipes, flushable wipes, and TPs. Essential statistics of the data are available in the last two rows of relevant tables. Our associated article provides interpretations and discussions of the data for further consideration [1]. The data include raw, and analyzed quantities as follows: 1- A tensile property, such as the maximum amount of force ($F_{\text{max}}$) that is needed to break a sample, was measured and reported as the average of seven readings for each sample, 2- A tensile property, such as tensile strength, was computed by dividing the measured $F_{\text{max}}$ value with width of a specimen. For convenience, we use sample no.1 in Table 11 as an example case to demonstrate step-by-step how we obtained tensile properties of a sample. Accordingly, we used the tensile instrument and measured the $F_{\text{max}}$, and the elongation-at-break values for each of seven specimens of a sample. We reported the arithmetic average of seven readings as the measured properties as shown below for sample no.1 in Table 11.

| Specimen no. of Sample 1. | $F_{\text{max}}$ (N) | Elongation at Break (% of a specimen length = 100 mm) |
|---------------------------|----------------------|------------------------------------------------------|
| 1–1                       | 26.03                | 32.33                                                |
| 1–1                       | 28.70                | 37.00                                                |
| 1–3                       | 28.05                | 32.88                                                |
| 1–4                       | 26.54                | 30.5                                                 |
| 1–5                       | 28.80                | 32.63                                                |
| 1–6                       | 25.64                | 33.29                                                |
| 1–7                       | 23.63                | 31.88                                                |
| Arithmetic average        | 26.77                | 32.93                                                |
| Reported value            | 27                   | 33                                                   |

Table 11
Tensile properties of dry non-flushable wipe samples from around the world. Tensile properties were quantified by using sheets that were dried at 40 °C for 24 h. Sample IDs indicate NF: Non-flushable wipe, and SN: Sample Number.

| No. | I.D.        | $F_{\text{max}}$ (N) | Tensile Strength (N/m) | Basis weight$^{(+)}$ (g/m²) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|-----|-------------|----------------------|------------------------|-----------------------------|----------------------|----------------------|------------------------|
| 1   | NF-SN-1     | 27                   | 1800                   | 52                          | 34.6                 | 3529                 | 33                     |
| 2   | NF-SN-2     | 4                    | 267                    | 55                          | 4.8                  | 494                  | 8.7                    |
| 3   | NF-SN-3     | 28                   | 1867                   | 59                          | 31.6                 | 3226                 | 36.4                   |
| 4   | NF-SN-4     | 12                   | 800                    | 48                          | 16.8                 | 1699                 | 22                     |
| 5   | NF-SN-5     | 4.6                  | 307                    | 47                          | 6.5                  | 665                  | 19.4                   |
| 6   | NF-SN-6     | 14.5                 | 967                    | 44                          | 21.9                 | 2240                 | 36                     |
| 7   | NF-SN-7     | 20                   | 1333                   | 40                          | 33.1                 | 3399                 | 35.7                   |
| 8   | NF-SN-8     | 15                   | 1000                   | 38                          | 26.1                 | 2683                 | 38.8                   |
| 9   | NF-SN-9     | 9                    | 600                    | 43                          | 14.0                 | 1423                 | 29                     |
| 10  | NF-SN-10    | 4                    | 267                    | 58                          | 4.6                  | 469                  | 7.4                    |
| 11  | NF-SN-11    | 30                   | 2000                   | 59                          | 34.1                 | 3457                 | 23.8                   |
| 12  | NF-SN-12    | 22                   | 1467                   | 55                          | 26.7                 | 2719                 | 21.9                   |
| 13  | NF-SN-13    | 9.4                  | 627                    | 51                          | 12.3                 | 1253                 | 12.3                   |
| 14  | NF-SN-14    | 20                   | 1333                   | 46                          | 28.7                 | 2956                 | 13.5                   |
| 15  | NF-SN-15    | 14.3                 | 953                    | 52                          | 18.4                 | 1869                 | 33.6                   |
| 16  | NF-SN-16    | 7                    | 467                    | 77                          | 6.1                  | 618                  | 3.5                    |
| Average Range             | 15                   | 1003                   | 51                        | 20.0                | 2044                 | 23.4                   |

$^{(+)}$ Basis weight values were obtained from Table 2 of this article.
### Table 12
Wet tensile properties of non-flushable wipe samples from around the world. Tensile properties were quantified by using wet sheets of the samples. Sample IDs indicate NF: Non-flushable wipe, and SN: Sample Number.

| No. | I.D.  | $F_{\text{max}}$ (N) | Tensile Strength (N/m) | Basis weight$^+$ (g/m²) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|-----|-------|----------------------|------------------------|------------------------|----------------------|----------------------|-------------------------|
| 1   | NF-SN-1 | 28                   | 1867                   | 175                    | 10.7                 | 1088                 | 33                      |
| 2   | NF-SN-2 | 3                    | 200                    | 215                    | 0.9                  | 95                   | 62                      |
| 3   | NF-SN-3 | 26.8                 | 1787                   | 207                    | 8.6                  | 880                  | 43                      |
| 4   | NF-SN-4 | 19.3                 | 1287                   | 137                    | 9.4                  | 958                  | 22.7                    |
| 5   | NF-SN-5 | 25                   | 1667                   | 166                    | 10.0                 | 1024                 | 30.1                    |
| 6   | NF-SN-6 | 20.6                 | 1373                   | 124                    | 11.1                 | 1129                 | 38.7                    |
| 7   | NF-SN-7 | 25.1                 | 1673                   | 108                    | 15.5                 | 1580                 | 38.2                    |
| 8   | NF-SN-8 | 14.2                 | 947                    | 95                     | 10.0                 | 1016                 | 36.6                    |
| 9   | NF-SN-9 | 13.1                 | 873                    | 134                    | 6.5                  | 665                  | 25.9                    |
| 10  | NF-SN-10| 2.2                  | 147                    | 168                    | 0.9                  | 89                   | 15.6                    |
| 11  | NF-SN-11| 18.4                 | 1227                   | 196                    | 6.3                  | 638                  | 23.3                    |
| 12  | NF-SN-12| 15.4                 | 1027                   | 191                    | 5.4                  | 548                  | 20.7                    |
| 13  | NF-SN-13| 6.8                  | 453                    | 232                    | 2.0                  | 199                  | 15                      |
| 14  | NF-SN-14| 10.3                 | 687                    | 205                    | 3.3                  | 342                  | 12.5                    |
| 15  | NF-SN-15| 15.3                 | 1020                   | 94                     | 10.9                 | 1106                 | 34                      |
| 16  | NF-SN-16| 2.1                  | 140                    | 152                    | 0.9                  | 94                   | 3.4                      |

Average: 15, 1023, 162, 7, 715, 28

Range: 2.1–28, 140–1867, 94–232, 0.9–15.5, 89–1580, 3.4–62

$s^*$: 9 580 44 4 453 14

$\varepsilon^*$: 2 145 11 1 113 4

* $s^*$ means standard deviation, and $\varepsilon^*$ means standard error.

$+$ Basis weight values were obtained from Table 1 of this article.

### Table 13
Tensile properties of dry flushable wipe samples from North America. Tensile properties were quantified by using sheets that were dried at 40 °C for 24 h. Sample IDs indicate NA: North America (flushable), and SN: Sample Number.

| No. | I.D.  | $F_{\text{max}}$ (N) | Tensile Strength (N/m) | Basis weight$^+$ (g/m²) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|-----|-------|----------------------|------------------------|------------------------|----------------------|----------------------|-------------------------|
| 1   | NA-SN-1| 5.5                  | 367                    | 62                     | 5.9                  | 606                  | 4.6                      |
| 2   | NA-SN-2| 5.4                  | 360                    | 64                     | 5.6                  | 578                  | 4.6                      |
| 3   | NA-SN-3| 6.2                  | 413                    | 80                     | 5.2                  | 529                  | 10.5                     |
| 4   | NA-SN-4| 6.1                  | 407                    | 81                     | 5.0                  | 512                  | 11.4                     |
| 5   | NA-SN-5| 6                   | 400                    | 79                     | 5.1                  | 519                  | 11.1                     |
| 6   | NA-SN-6| 6.6                  | 440                    | 74                     | 5.9                  | 609                  | 18.5                     |
| 7   | NA-SN-7| 4.2                  | 280                    | 59                     | 4.7                  | 481                  | 8.4                      |
| 8   | NA-SN-8| 5.1                  | 340                    | 67                     | 5.1                  | 515                  | 4.7                      |
| 9   | NA-SN-9| 5.7                  | 380                    | 67                     | 5.7                  | 576                  | 5.6                      |
| 10  | NA-SN-10| 17.8                | 1187                   | 70                     | 17.0                 | 1724                 | 21.6                     |
| 11  | NA-SN-11| 2.8                 | 187                    | 53                     | 3.5                  | 358                  | 7.8                      |
| 12  | NA-SN-12| 6                   | 400                    | 79                     | 5.1                  | 517                  | 10.6                     |
| 13  | NA-SN-13| 3.5                 | 233                    | 61                     | 3.8                  | 390                  | 11                       |
| 14  | NA-SN-14| 7                   | 467                    | 55                     | 8.5                  | 863                  | 12                       |
| 15  | NA-SN-15| 7.2                 | 480                    | 58                     | 8.3                  | 845                  | 9.2                      |
| 16  | NA-SN-16| 37.4                | 2493                   | 51                     | 48.9                 | 4954                 | 30                       |

Average: 5.5, 368, 66, 5.5, 564, 9.3

Range: 2.8–37.4, 187–2493, 51–81, 3.5–48.9, 358–4954, 4.6–30

$s^*$: 1.3 85 10 1.4 142 3.8

$\varepsilon^*$: 0.3 23 2 0.4 38 1.0

* $s^*$ means standard deviation, and $\varepsilon^*$ means standard error.

$+$ Basis weight values were obtained from Table 3 of this article.

* $b$ Samples 10 and 16 were excluded from statistical analysis due to their oddly high $F_{\text{max}}$ values.
By using the measured quantities and the equations below, we estimated tensile strength, tensile index, and breaking length of a sample as follows

Tensile Strength = \( \frac{F_{\text{max}}}{\text{width of a specimen}} \)

The \( F_{\text{max}} \) value for sample no. 1 (NF-SN-1) was reported as 27 N in Table 11, and width of a specimen was 15 mm = 0.015 m. Hence, tensile strength is \( \frac{27}{0.015} = 1800 \text{ N/m} \) as shown in the fourth column of Table 11. Likewise, tensile index is

Tensile Index = Tensile Strength/Basis weight

Basis weight of sample no. 1 (NF-SN-1) in Table 11 was obtained as 52 g/m² from Table 2 of this article. Accordingly, Tensile Index is \( \frac{1800 \text{ (N/m)}}{52 \text{ (g/m²)}} = 34.6 \text{ Nm/g} \) for the sample (6th column of Table 11). Finally, breaking length is

Breaking Length = Tensile Index (Nm/g)/Gravitational Acceleration

Breaking Length of a sample is the length at which the sample will break due to its own weight. Accordingly, breaking length for sample no. 1 (NF-SN-1) in Table 11 is \( \frac{34.6 \text{ (Nm/g)}}{9.807 \text{ (m/s²)}} = 3.529 \text{ m} \).

### Table 14
Wet tensile properties of flushable wipe samples from North America. Tensile properties were quantified by using wet sheets of the samples. Sample IDs indicate NA: North America (flushable), and SN: Sample Number.

| No. | I.D.     | \( F_{\text{max}} \) (N) | Tensile Strength (N/m) | Basis weight\(^{+1}\) (g/m²) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|-----|----------|--------------------------|------------------------|-----------------------------|---------------------|---------------------|-------------------------|
| 1   | NA-SN-1  | 3.5                      | 233                    | 210                         | 1.1                 | 113                 | 16.9                    |
| 2   | NA-SN-2  | 3.4                      | 227                    | 220                         | 1.0                 | 105                 | 16.3                    |
| 3   | NA-SN-3  | 1.5                      | 100                    | 202                         | 0.5                 | 51                  | 12.8                    |
| 4   | NA-SN-4  | 1.4                      | 93                     | 206                         | 0.5                 | 46                  | 15.4                    |
| 5   | NA-SN-5  | 1.5                      | 100                    | 218                         | 0.5                 | 47                  | 14.7                    |
| 6   | NA-SN-6  | 1.4                      | 93                     | 194                         | 0.5                 | 49                  | 13.8                    |
| 7   | NA-SN-7  | 1.5                      | 100                    | 170                         | 0.6                 | 60                  | 14                      |
| 8   | NA-SN-8  | 2.6                      | 173                    | 209                         | 0.8                 | 85                  | 14.2                    |
| 9   | NA-SN-9  | 2.8                      | 187                    | 212                         | 0.9                 | 90                  | 12.7                    |
| 10  | NA-SN-10 | 18.1                     | 1207                   | 311                         | 3.9                 | 395                 | 26.1                    |
| 11  | NA-SN-11 | 2.2                      | 147                    | 171                         | 0.9                 | 88                  | 17                      |
| 12  | NA-SN-12 | 1.8                      | 120                    | 203                         | 0.6                 | 60                  | 13.4                    |
| 13  | NA-SN-13 | 3.1                      | 207                    | 216                         | 1.0                 | 98                  | 21                      |
| 14  | NA-SN-14 | 2.9                      | 193                    | 164                         | 1.2                 | 120                 | 15                      |
| 15  | NA-SN-15 | 2.8                      | 187                    | 186                         | 1.0                 | 102                 | 15.4                    |
| 16  | NA-SN-16 | 4.0                      | 2667                   | 311                         | 19.1                | 1949                | 30                      |

Average: 2.3 \( \pm \) 0.2, Basis weight \( \pm \) 14, Tensile Index \( \pm \) 52, Breaking Length \( \pm \) 1949

**Range:** 1.4 – 40, 93 – 2667, 140 – 311, 0.5 – 18.1, 46 – 1949, 12.7 – 30

\( s^* \): Mean, standard deviation; \( \epsilon^* \): Standard error.

By using the measured quantities and the equations below, we estimated tensile strength, tensile index, and breaking length of a sample as follows

Tensile Strength = \( F_{\text{max}}/\text{width of a specimen} \)

The \( F_{\text{max}} \) value for sample no. 1 (NF-SN-1) was reported as 27 N in Table 11, and width of a specimen was 15 mm = 0.015 m. Hence, tensile strength is \( 27/0.015 = 1800 \text{ N/m} \) as shown in the fourth column of Table 11. Likewise, tensile index is

Tensile Index = Tensile Strength/Basis weight

Basis weight of sample no. 1 (NF-SN-1) in Table 11 was obtained as 52 g/m² from Table 2 of this article. Accordingly, Tensile Index is \( 1800 \text{ (N/m)} / 52 \text{ (g/m²)} = 34.6 \text{ Nm/g} \) for the sample (6th column of Table 11). Finally, breaking length is

Breaking Length = Tensile Index (Nm/g)/Gravitational Acceleration

Breaking Length of a sample is the length at which the sample will break due to its own weight. Accordingly, breaking length for sample no. 1 (NF-SN-1) in Table 11 is \( 34.6 \text{ (Nm/g)} \times 1000 \text{ (g/kg)} / 9.807 \text{ (m/s²)} = 3.529 \text{ m} \).

2. **Experimental design, materials, and methods**

2.1. **Microscopic thickness measurements**

For thickness measurements, we used a light microscope, (Leica VMHT MOT, Leica Microsystems GmbH, Wetzlar, Germany) at 100× magnification. This microscope can measure thicknesses as low as 50 \( \mu \text{m} \) at increments of 1 \( \mu \text{m} \). Fig. 2 illustrates with photographs how sheet thicknesses were quantified for each wipe or TP sample.
Table 15
Tensile properties of dry flushable wipe samples from European, and from Far Eastern countries. Tensile properties were quantified by using sheets that were dried at 40 °C for 24 h. Sample IDs indicate EU: Europe (flushable), FE: Far East (flushable), and SN: Sample Number.

| No. | LD.     | Fmax (N) | Tensile Strength (N/m) | Basis weight\(^{\dagger}\) (g/m\(^2\)) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|-----|---------|----------|------------------------|------------------------------------------|----------------------|----------------------|-------------------------|
| 1   | EU-SN-1 | 6        | 400                    | 59                                       | 6.8                  | 691                  | 10                      |
| 2   | EU-SN-2 | 5.8      | 387                    | 55                                       | 7.0                  | 722                  | 10.2                    |
| 3   | EU-SN-3 | 4.2      | 280                    | 63                                       | 4.4                  | 454                  | 14                      |
| 4   | EU-SN-4 | 8.1      | 540                    | 65                                       | 8.3                  | 852                  | 9                       |
| 5   | EU-SN-5 | 6        | 400                    | 65                                       | 6.2                  | 624                  | 9                       |
| 6   | EU-SN-6 | 5.9      | 393                    | 52                                       | 7.6                  | 775                  | 8.8                     |
| 7   | EU-SN-7 | 5.9      | 393                    | 48                                       | 8.2                  | 844                  | 9                       |
| 8   | EU-SN-8 | 6        | 400                    | 63                                       | 6.3                  | 650                  | 10                      |
| 9   | EU-SN-9 | 6        | 400                    | 68                                       | 5.9                  | 604                  | 10                      |
| 10  | EU-SN-10| 5.4      | 360                    | 54                                       | 6.7                  | 684                  | 14                      |
| 11  | EU-SN-11| 5.2      | 347                    | 69                                       | 5.0                  | 516                  | 8                       |
| 12  | EU-SN-12| 3.9      | 260                    | 60                                       | 4.3                  | 439                  | 14                      |
| 13  | EU-SN-13| 6.5      | 433                    | 59                                       | 7.3                  | 744                  | 14                      |
| 14\(^{(a)}\) | EU-SN-14| 17.4     | 993                    | 52                                       | 19.1                 | 1946                 | 24                      |
| 15  | EU-SN-15| 5.5      | 367                    | 56                                       | 6.6                  | 664                  | 5                       |
| 16  | EU-SN-16| 5.3      | 353                    | 60                                       | 5.9                  | 605                  | 9.2                     |
| 17  | EU-SN-17| 2.6      | 173                    | 64                                       | 2.7                  | 276                  | 5                       |
| 18  | EU-SN-18| 6.4      | 427                    | 67                                       | 6.4                  | 653                  | 12                      |
| 19  | FE-SN-1 | 3.4      | 227                    | 42                                       | 5.4                  | 691                  | 17                      |
| 20  | FE-SN-2 | 4.1      | 273                    | 39                                       | 7.0                  | 722                  | 16                      |
| 21  | FE-SN-5 | 3.4      | 227                    | 44                                       | 5.2                  | 454                  | 8.1                     |
| 22  | FE-SN-6 | 3.5      | 233                    | 53                                       | 4.4                  | 852                  | 8.3                     |
| 23\(^{(b)}\) | FE-SN-8| 13       | 500                    | 53                                       | 9.4                  | 624                  | 7.4                     |
| **Average** | **6.0** | **381** | **57**                 | **6.8**                                  | **700**              | **11.1**             |                         |
| **Range** | **2.6–17.4** | **173–993** | **39–69**                | **2.7–19.1**                      | **276–1946**         | **5–24**              |                         |

\(^{(a)}\) Sample 14 was excluded from statistical analysis due to its unusually high Fmax value. A few samples from Far Eastern Countries were omitted from this list due to inconsistent readings.

\(^{(b)}\) Sample weight values were obtained from Table 6 of this article.

\(^{*}\) “s” means standard deviation, and “ε” means standard error.

2.2. Tensile properties of nonwoven wipes and toilet papers

Tensile properties of dry samples were measured according to standard method of ISO 12625 - Part 4: Tissue paper and tissue products — Determination of (dry) tensile strength, and stretch at break by using tensile apparatus operating with constant rate of elongation. We used a universal tensile testing machine (Schimadzu AG-IC, Tokyo, Japan) that was controlled by Trapezium X Materials Testing Software. The tensile instrument has two jaws with clamps that hold a strip of a sample in place during testing. The bottom jaw is fixed, while the upper jaw elongates a strip during a test run. For calibration of the instrument, we tested standard printing paper, toilet papers, and standard cardboard, for which tensile properties were available. Then, we prepared a single strip of a wipe (or TP) as 15 mm in width and >100 mm in length, and placed exactly 100 mm between jaws of the tensile machine. During testing, the upper jaw pulled a strip upwards, while the Trapezium X software controlled rates of loading, and separation of jaws. Force was applied at increments of 0.1 N, while the jaws were separated at a constant rate of 25 mm/min, and each strip broke between 15 and 30 seconds. Collectively, these steps confirmed constant rate of elongation for each strip as required by the ISO method. In accordance, we took 5 to 7 measurements for each specimen, and we rejected any strip that broke near jaws. In addition, we tested samples in their machine directions (MD), and in their cross directions (CD), and we report the results in MD to be succinct. Fig. 3 shows the instrument, and a close-up view of a strip fastened to the instrument.
Table 16
Wet tensile properties of flushable wipe samples from European, and from Far Eastern countries. Tensile properties were quantified by using wet sheets of the samples. Sample IDs indicate EU: Europe (flushable), FE: Far East (flushable), and SN: Sample No.

| No. | I.D.     | F max (N) | Tensile Strength (N/m) | Basis weight(þ) (g/m²) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|-----|----------|-----------|------------------------|-------------------------|----------------------|---------------------|-------------------------|
| 1   | EU-SN-1  | 2         | 133                    | 168                     | 0.8                  | 81                  | 10.3                    |
| 2   | EU-SN-2  | 2         | 133                    | 160                     | 0.8                  | 85                  | 10                      |
| 3   | EU-SN-3  | 2.4       | 160                    | 222                     | 0.7                  | 73                  | 16                      |
| 4   | EU-SN-4  | 3.3       | 220                    | 196                     | 1.1                  | 114                 | 16                      |
| 5   | EU-SN-5  | 2.2       | 133                    | 201                     | 0.7                  | 68                  | 14                      |
| 6   | EU-SN-6  | 2.3       | 153                    | 141                     | 1.1                  | 111                 | 11                      |
| 7   | EU-SN-7  | 2.4       | 160                    | 117                     | 1.4                  | 111                 | 11                      |
| 8   | EU-SN-8  | 2         | 133                    | 195                     | 0.7                  | 69                  | 13                      |
| 9   | EU-SN-9  | 2         | 133                    | 195                     | 0.7                  | 70                  | 14                      |
| 10  | EU-SN-10 | 2.1       | 140                    | 177                     | 0.8                  | 81                  | 12                      |
| 11  | EU-SN-11 | 3.5       | 233                    | 227                     | 1.0                  | 105                 | 19                      |
| 12  | EU-SN-12 | 1.7       | 113                    | 167                     | 0.7                  | 69                  | 10                      |
| 13  | EU-SN-13 | 2.5       | 167                    | 159                     | 1.1                  | 107                 | 15                      |
| 14  | EU-SN-14 | 15.5      | 1240                   | 178                     | 7.0                  | 711                 | 19                      |
| 15  | EU-SN-15 | 3.5       | 233                    | 168                     | 1.4                  | 141                 | 16                      |
| 16  | EU-SN-16 | 2.5       | 167                    | 233                     | 0.7                  | 75                  | 16                      |
| 17  | EU-SN-17 | 2.3       | 153                    | 234                     | 0.7                  | 67                  | 16.9                    |
| 18  | EU-SN-18 | 3.6       | 240                    | 244                     | 1.0                  | 100                 | 17                      |
| 19  | FE-SN-1  | 2.2       | 147                    | 127                     | 1.8                  | 182                 | 17                      |
| 20  | FE-SN-2  | 2.4       | 160                    | 111                     | 2.5                  | 251                 | 16                      |
| 21  | FE-SN-5  | 1.5       | 100                    | 159                     | 1.4                  | 146                 | 12                      |
| 22  | FE-SN-6  | 1.4       | 93                     | 152                     | 1.5                  | 156                 | 6.9                     |
| 23  | FE-SN-8  | 1.3       | 87                     | 136                     | 3.7                  | 375                 | 0.6                     |
|     |          | Average   | 2.9                    | 201                     | 177                  | 1.4                 | 147                     | 13.5                    |
|     |          | Range     | 1.3–15.5               | 87–1240                 | 0.7–7                | 67–711              | 0.6–19                  |
|     |          | s*        | 0.63                  | 44                     | 39                   | 0.7                 | 73                     | 4.2                     |
|     |          | ε*        | 0.14                  | 9                      | 8                    | 0.15                | 15                     | 0.9                     |

* “s” means standard deviation, and “ε” means standard error.

Basis weight values were obtained from Table 5 of this article.

Sample 14 was excluded from statistical analysis due to its unusually high F max value. A few samples from Far Eastern Countries were omitted from this list due to inconsistent readings.

Table 17
Tensile properties of toilet paper samples. Tensile properties were quantified by using sheets that were dried at 40 °C for 24 h. The values are listed in the order of F max values as the highest one on top.

| Sample No. | F max (N) | Tensile Strength (N/m) | Basis weight (g/m²) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|------------|-----------|------------------------|---------------------|----------------------|---------------------|------------------------|
| 1          | 5.4       | 358                    | 50                  | 7.2                  | 730                 | 16.8                   |
| 2          | 4.6       | 304                    | 49                  | 6.2                  | 633                 | 17.8                   |
| 3          | 4.5       | 300                    | 57                  | 6.1                  | 537                 | 13.4                   |
| 4          | 4.1       | 274                    | 39                  | 7.0                  | 717                 | 18.3                   |
| 5          | 2.8       | 185                    | 41                  | 4.5                  | 464                 | 10.5                   |
| 6          | 2.5       | 167                    | 44                  | 3.3                  | 617                 | 12.1                   |
| 7          | 2.5       | 167                    | 34                  | 3.7                  | 431                 | 11.8                   |
| 8          | 2.4       | 160                    | 17                  | 9.8                  | 480                 | 5.8                    |
| 9          | 2.2       | 160                    | 28                  | 5.7                  | 340                 | 7.5                    |
| 10         | 1.9       | 127                    | 39                  | 3.3                  | 380                 | 7.5                    |
| 11         | 1.6       | 107                    | 26                  | 4.1                  | 411                 | 3.7                    |
|            | Average   | 3.1                   | 210                 | 38.5                 | 5.5                 | 522                    | 11.3                   |
|            | Range     | 1.6–5.4               | 107–358             | 17–57                | 3.3–9.8             | 340–730               | 3.7–18.3               |
|            | s*        | 1.3                   | 84                  | 12                   | 2                   | 135                    | 5                      |
|            | ε*        | 0.4                   | 25                  | 4                    | 0.6                 | 41                     | 1.5                    |

* “s” means standard deviation, and “ε” means standard error.
Table 18
Tensile properties of toilet paper samples in their wet states. The samples are listed in the same order as in Table 17.

| Sample No. | $F_{\text{max}}$ (N) | Tensile Strength (N/m) | Basis weight (g/m²) | Tensile Index (Nm/g) | Breaking Length (m) | Elongation at Break (%) |
|------------|----------------------|------------------------|---------------------|---------------------|---------------------|------------------------|
| 1          | 0.28                 | 18.7                   | 50                  | 0.37                | 38                  | 4                      |
| 2          | 0.27                 | 18                     | 49                  | 0.37                | 37                  | 7                      |
| 3          | 0.5                  | 33                     | 57                  | 0.58                | 60                  | 8                      |
| 4          | 0.4                  | 26.7                   | 39                  | 0.68                | 70                  | 6                      |
| 5          | 0.28                 | 18.4                   | 41                  | 0.45                | 46                  | 6                      |
| 6          | 0.06                 | 4                      | 28                  | 0.14                | 15                  | 2                      |
| 7          | 0.13                 | 8.7                    | 39                  | 0.22                | 23                  | 2                      |
| 8          | 0.33                 | 22.1                   | 34                  | 0.65                | 66                  | 7                      |
| 9          | 0.38                 | 25                     | 44                  | 0.57                | 58                  | 8                      |
| 10         | 0.18                 | 12.2                   | 34                  | 0.36                | 37                  | 3                      |
| 11         | 0.025                | 1.7                    | 26                  | 0.1                 | 7                   | 1                      |
| **Average** | **0.26**             | **17.1**               | **40**              | **0.4**             | **41.5**            | **4.9**                |
| **Range**  | **0.025–0.5**        | **1.7–33**             | **26–57**           | **0.1–0.68**        | **7–70**            | **1–8**                |
| s*         | 0.15                 | 10                     | 9.5                 | 0.2                 | 21                  | 2.4                    |
| e*         | 0.04                 | 3                      | 3                   | 0.06                | 6                   | 0.7                    |

* "s" means standard deviation, and "e" means standard error.

Fig. 2. Sheet thickness measurements of wipes by using a light microscope (Leica VMHT MOT, Wetzlar, Germany). (a) General view of the microscope and its image processing software running on a personal computer. Cross-section of the wipe sample is shown on computer screen, where horizontal red lines indicate sheet thicknesses measured at various points along the cross-section. (b) Typical view of a wipe sample fastened vertically to sample holder.
Fig. 3. Measurement of tensile properties of nonwoven wipes and TPs by using universal tensile testing machine (Schimadzu AG-IC, Tokyo, Japan). (a) General view of the tensile testing machine, (b) Close-up view of the jaws where a strip was fastened for testing.

Fig. 4. Quantification of tensile properties of nonwoven wipes and TPs in wet states. Panel (a) shows that a single strip of moist wipe was rolled around and dipped into deionized water for saturation. Then, it was fastened to the jaws of the tensile instrument for testing as shown in Fig. 3. Panel (b) shows 6 strips of a TP that are rolled around and dipped into deionized water for saturation. By this approach, only the central part of TP strips were wetted, while the edges remained dry so that strips were fastened to the tensile machine properly. Panel (c) shows a typical view of wipe specimens after test runs. Panel (d) shows typical view of TP specimens after test runs. Each specimen in panel (d) is composed of 6 strips of a TP sample.
Tensile properties of wet samples were measured according to standard method of ISO 3871: Determination of tensile properties after immersion in water. For very absorbent papers such as TPs, the standard method indicates that only the central part of the test specimen should be wetted. In accordance with this guideline, we rolled around a strip like a circle, and dipped its central area into deionized water for 5 seconds for saturation with water. Then, we fastened the strip to the machine and started the tensile test immediately. Fig. 4 depicts the procedure, and pictures of strips after test runs. For TPs, we placed 3 or 6 strips on top of each other, wetted their central part, and conducted our testing. Using 3 or 6 strips of a TP allowed us to obtain reliable and repeatable readings, e.g., $F_{\text{max}}$ readings were well above the instrument’s minimum reading limit of 0.1 N. Then, we divided the measured $F_{\text{max}}$ by the number of strips to estimate the $F_{\text{max}}$ value for a single sheet. Standard deviation ($s$) and standard error ($\epsilon$) of $F_{\text{max}}$ values for wet TPs were 0.15, and 0.04, respectively, while the mean (average) $F_{\text{max-wet}}$ value was 0.26 N for TPs (Tables 17 and 18). Accordingly, standard deviation was $(0.15/0.26) \times 100 = 58\%$, and standard error was $(0.04 \text{ N}/0.26 \text{ N}) = 0.15 \times 100 = 15\%$ of the average $F_{\text{max}}$ value of 0.26 N. The relatively high $s$ and $\epsilon$ values are attributable to material compositions of TP samples. Briefly, fiber types (e.g., hardwood, softwood), their mixing ratios, fiber strength, fiber dimensions, as well as, types and amounts of binders and wet strength resins that are used to form a final product collectively influence that product’s strength in its dry, and in its wet states. Hence, $F_{\text{max}}$ quantities varied considerably for TPs in their wet states as indicated by the $s$ and $\epsilon$ values of our measurements.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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