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DOI
10.1007/978-3-030-80288-2_20

Publication date
2021

Document Version
Final published version

Published in
Advances in Safety Management and Human Performance - Proceedings of the AHFE 2021 Virtual Conferences on Safety Management and Human Factors, and Human Error, Reliability, Resilience, and Performance, 2021

Citation (APA)
Nguyên, N. N., Loon, J. V., Bois, E. D., Verlinden, J., Verwulgen, S., & Watts, R. (2021). Experimental Comparison of CWA 17553:2020 Community Face Coverings to Surgical Masks and Filtering Facepiece Respirators. In P. M. Arezes, & R. L. Boring (Eds.), *Advances in Safety Management and Human Performance - Proceedings of the AHFE 2021 Virtual Conferences on Safety Management and Human Factors, and Human Error, Reliability, Resilience, and Performance, 2021* (pp. 169-177). (Lecture Notes in Networks and Systems; Vol. 262 LNNS). Springer. https://doi.org/10.1007/978-3-030-80288-2_20

Experimental Comparison of CWA 17553:2020 Community Face Coverings to Surgical Masks and Filtering Facepiece Respirators

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Abstract. With the worldwide spread of the COVID-19 virus in early 2020, shortages of surgical masks and filtering facepiece respirator (FFR) masks became a critical problem. European governments recommended that civilians should not use these masks so that the shortages in the hospitals would be minimised. In Europe, civilians were instead advised to wear community face coverings. In June 2020, the European Committee for Standardisation (CEN) published CWA 17553:2020 [1–3] which formalised minimum requirements, methods of testing and use of community face coverings. The CWA 17553 is presently only a recommendation, and not an official standard such as the EN14683 standard for surgical masks or the EN149 standard for filtering facepiece respirators. Because there are different performance requirements for these three different classes of masks, it makes comparing their performance challenging. In this work, we perform particulate filtration efficiency measurement, total inward leakage measurement and breathability measurement on a range of surgical masks, filtering facepiece respirators and community face coverings. This analysis provides a useful comparison between material performance and the effectiveness of a mask's design which is manufactured from this material.

Keywords: Community face coverings · Surgical masks · Filtering facepiece respirators

1 Introduction

With the worldwide spread of the COVID-19 virus in early 2020, shortages of surgical masks and filtering facepiece respirator (FFR) masks became a critical problem. European governments recommended that civilians should not use these masks so that the shortages in the hospitals would be minimised. In Europe, civilians were instead advised to wear community face coverings. These community coverings could be made by the civilians themselves or they could be purchased through vendors. In June 2020, the European Committee for Standardisation (CEN) published CWA 17553:2020 which

P. M. Arezes and R. L. Boring (Eds.): AHFE 2021, LNNS 262, pp. 169–177, 2021.
https://doi.org/10.1007/978-3-030-80288-2_20

formalised minimum requirements, methods of testing and use of community face coverings [2]. The CWA 17553 is presently only a recommendation, and not an official standard such as the EN14683:2019 + AC:2019 standard for surgical masks [3] or the EN149:2001+A1:2009 standard for filtering facepiece respirators [4].

For important performance specifications like material filtration efficiency, the CWA 17553 targets two levels of filtration efficiency; 70% and 90%. Presently, manufacturers of community face coverings can use test results from the ISO/TC 94/SC 15, EN149 or EN14683, even though the size of the challenge particles used in these standards differ by a factor of ten. For example, the EN14683 measures filtration efficiency using bacteria with a size distribution around 3 μm and the EN149 uses NaCl and paraffin oil with size distributions around 0.3 μm. This makes comparisons of the same mask between the different test standards difficult.

In this work, we perform a suit of measurements to compare of community face coverings, with or without external filter inserts, with a range of EN14683-certified surgical masks, both cup-style and folding FFP2 and FFP3-certified respirator masks, KN95-certificated respirator masks, and prototype FFP2 and FFP3 respirator masks certified by the Belgian alternative testing protocol (ATP) [6] for FFP2/FFP3. Tests included total inward leakage (TIL) measured using the PALAS [8] Mas-Q-Check with standard European headform model (the Sheffield head), TIL measured using TSI Portacount instrumentation and human participants, particle filtration efficiency (PFE) measurement using the PALAS Mas-Q-Check, and breathing resistance using a Fluke airflow meter. The work is concluded with a discussion about material selection and how this can be linked to the effectiveness of a mask's design.

2 Comparing Performance Requirements

A standard is a requirement. they provide rules and guidelines for manufactures. in europe these standards are identified with an unique reference code which contain the letters "EN" ("European Standards", 2021). These European standards are approved by one of the three recognized European Standardization Organizations (ESOs): Comité Européen de Normalisation (CEN), Comité Européen de Normalisation Electrotechnique (CENELEC), European Telecommunications Standards Institute (ETSI). We will discuss the standards that are relevant for the medical face masks, ffr and community face coverings (CFCs). This section provides a comparison between the technical performance requirements for the EN149, EN14683 and CWA 17553. The technical requirements for filter performance, total inward leakage and breathing resistance are shown in Tables 1, 2 and 3, respectively.

EN149 Standard

Firstly, FFRs in European countries need to comply with the EN149:2001+ A1:2009 standard [5, 6]. FFRs are classified according to the penetration of filter material and their maximum total inward leakage (TIL). They also need to meet the requirements for the breathing resistance. The EN149 standard divides the FFRs in three classes: FFP1, FFP2 and FFP3. For the penetration test, the filter material is challenged with test aerosols of both NaCl and paraffin oil. The particle size distribution of the NaCl shall be 0.02 μm to 2 μm equivalent aerodynamic diameter with a mass median diameter of 0.6 μm. The total inward leakage (TIL) measures the particulate leakage into the respirator mask. The maximum permissible TIL is the arithmetic mean of leakage measured over a number of exercises for a number of users. The limits are set as: FFP1 = 22%, FFP2 = 8%, FFP3 = 2% (CEN, 2009). Breathing resistance measures the amount of pressure needed to breathe through the material. This is separated by inhalation and exhalation resistance. The maximum permitted inhalation resistance is set by the different classification, for example FFP1, FFP2 and FFP3, and are measured for moderate (30 l/min) and heavy (95 l/min) inhalation rates. The maximum permitted exhalation resistance is uniform across the classifications and measured at a rapid exhalation rate (160 L per minute).

EN14683 Standard

EN14683 standard is a standard that all medical face masks in the European countries need to comply with [5, 6]. These medical face masks are divided in three types: Type I, Type II and Type IIR. An important criteria is the Bacterial filtration efficiency (BFE).The material is tested with living bacteria (Staphylococcus aureus) with the mean size of 3 (± 0.3) μm. Another important criteria is the breathing resistance of the material, described as the differential pressure. The maximum permitted differential pressure is divided again into the three types of medical face masks.

CWA 17553 Guideline

CWA 17553 is a guide that is recommended, but it is not mandatory [6]. This guide has been drafted for community masks. The filtration efficiency of the material is again an important criteria. The material is tested with particles with the size of 3 (± 0.5) μm (NaCl, paraffin oil), with two classified performance levels: Level 70% (greater than or equal to 70%) and level 90% (greater than or equal to 90%). Breathing resistance for the CWA 17553 guideline is equivalent to the inhalation and exhalation performance of the FFP2-class EN149 respirator.

The three standards have different requirements. The Particle Filtration Efficiency (PFE) is a criteria that the EN149 standard and the CWA 17553 have in common. For the EN149 standard they use Penetration of filter material as criteria. With the Penetration of filter material, the PFE can be calculated (Particle Filtration Efficiency (PFE) = 100% - Penetration of filter material). The EN14683 standard uses the Bacterial filtration efficiency (BFE) instead of the PFE. The BFE test uses live bacteria whereas the PFE test uses non-living particles. Beside the difference between the PFE and the BFE, each standard also uses different particle size distributions as reference for the tests. The EN149 standard and the CWA 17553 uses the same particles but they differ in size distribution. For the EN149 standard, the particle size distribution needs be approximately 0.3μm (NaCl, paraffin oil). For the CWA 17553 the particle size distribution needs to be 3 (± 0.5) μm (NaCl, paraffin oil). And the EN14683 standard uses living bacteria with a size distribution of 3 (± 0.3) μm (Staphylococcus aureus).

The Total inward leakage is a criteria that is only included in the EN149 standard. The EN14683 and the CW17553 do not include this in the standards.

The breathability criteria for the three standards are different too. In the EN14683 standard, the flow and whether it applies to the inhalation or exhalation is not specified. For the breathability, the EN149 standard has different flow ratings. For both the EN149 standard and the CWA 17553 there is a distinction between inhalation and exhalation. Each class has a different rating except for the CWA 17553. The CWA 17553 uses

Table 1. Comparison of filtration efficiency between the various classes of European masks

Filtration efficiency	PFE/BFE	Particles/bacteria	Size distribution	Value per class
EN149 standard	PFE	NaCl, paraffin oil (Particles)	0.3 μm	FFP1 = 80% FFP2 = 94% FFP3 = 99%
EN14683 standard	BFE	Staphylococcus aureus (Bacteria)	3 (± 0.3) μm	Type I = 95% Type II = 98% Type IIR = 98%
CWA 17553	PFE	NaCl, paraffin oil (Particles)	3 (± 0.5) μm	Level 70% = 70% Level 90% = 90%

Table 2. Comparison of total inward leakage between the various classes of European masks

Total inward leakage	Value per class
EN149 standard	FFP1 = 22% FFP2 = 8% FFP3 = 2%
EN14683 standard	–
CWA 17553	–

95 l/min as flow and the ratings are the same as that of the FFP2 class from the EN149 standard.

At the time of writing, there is no uniformity in the criteria among these standards and guidelines for the CFCs. These standards use different test variables. This is the reason why it is difficult to compare the masks with each other based on the existing standards. In the following we will try to compare the community face coverings with the medical face mask and FFR masks. For the comparison we will perform uniform test procedures to define the values. This procedure consist of three tests: PFE, TIL and Breathability.

3 Methods and Tested Materials

In this work, we performed three tests. These are the Particle Filtration Efficiency (PFE), Total Inward Leakage (TIL) and the Breathability. The PFE test checks the filter efficiency of the material of the mask. The value of the PFE is expressed in percentage. The higher the percentage; the better the PFE. For the PFE the PALAS Mas-Q-Check is used ("Mas-Q-Check", 2021). The Mas-Q-Check is a particle counting measurement device. This particular model provides a suction with a volume flow of 9.5 l/min. The Mas-Q-Check has two openings. One measures the ambient air and the other measures behind the material. It uses an aerosol spectrometer to measure the particle contamination in the ambient air. Afterwards the device the switches and determines the value of the particle

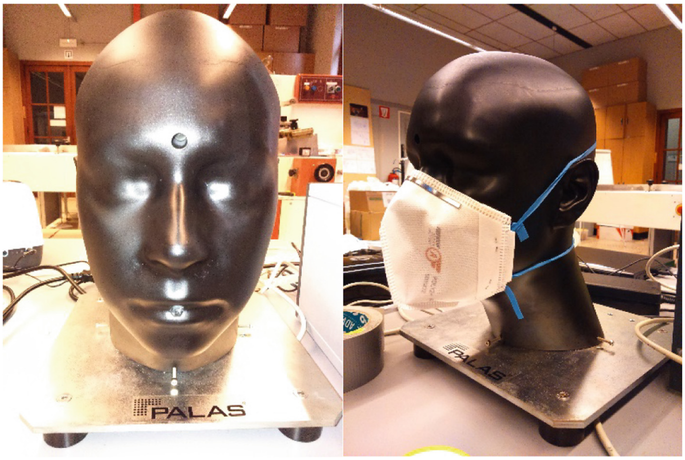
Table 3. Comparison of breathability between the various classes of European masks

Breathability	Flow	Inhalation per class	Exhalation per class
EN149 standard	30 l/min (Inhalation)	FFP1 = 0.6 mbar	
		FFP2 = 0.7 mbar	
		FFP3 = 1.0 mbar	
	95 l/min (Inhalation)	FFP1 = 2.1 mbar	
		FFP2 = 2.4 mbar	
		FFP3 = 3.0 mbar	
	160 l/min (Exhalation)		FFP1, FFP2, FFP3 = 3.0 mbar
EN14683 standard	Not stated (capable measuring 8 l/min)	Type I = 0.4 mbar/cm^2	Type I = 0.4 mbar/cm^2
		Type II = 0.4 mbar/cm^2	Type II = 0.4 mbar/cm^2
		Type IIR = 0.6 mbar/cm^2	Type IIR = 0.6 mbar/cm^2
		(Not stated for inhalation or exhalation)	(Not stated for inhalation or exhalation)
CWA 17553	95 l/min	level 70% = 2.4mbar	level 70% = 3.0 mbar
		level 90% = 2.4 mbar	level 90% = 3.0 mbar

contamination behind the material of the masks. It can measure particles with sizes from 140 nm to 1 μm. This process is repeated several times. The ratio of the two measured values is used to determine the PFE.

The TIL test checks the inward leakage of the mask. For this test the PALAS Mas-Q-Check is going to be used with a Sheffield head, as shown in Fig. 2. This head is the standard European headform model. The head has two holes. The small hole in the forehead measures the particle contamination in the ambient air. The hole between the lips measures the particle contamination behind the mask. By comparing the two values, the instrument calculates the TIL. The difference between the PFE and the TIL is that the PFE tests the material whereas the TIL tests the seal/mask shape (Fig. 1).

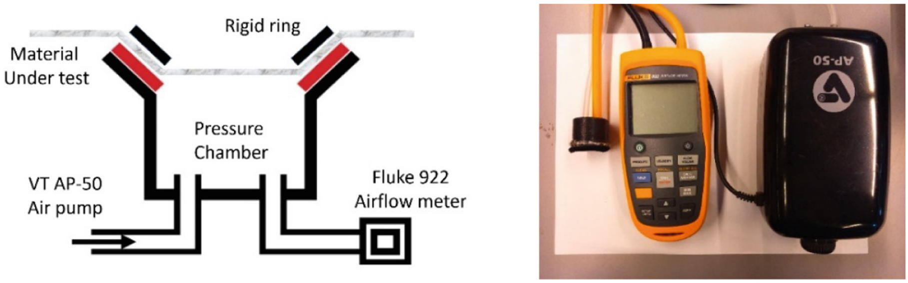
The breathability tests the breathing resistance of the material. The lower the resistance the better. A higher resistance will increase the difficulty to breathe. For this test, a test bench was developed to measure back pressure. The measurement system consists of an AP-50 air pump (VT Velda BV, Belgium), capable of generating a maximum flow of 5.5 l/min, a Fluke 922 Airflow Meter (Fluke Corporation, WA, USA) and a 3D-printed pressure chamber, consisting of adapters for tubes, and foam seat and rigid sealing ring to make an airtight seal with the material under test. This test setup is shown



(a) (b)

Fig. 1. (a) Sheffield headform used with the PALAS Mas-Q-Check and (B) the headform with a prototype Antwerp Design Factory Poly2+ FFP2 flat-folding respirator on it.

in Fig. 3, where the foam seat is shown in red. The test setups in the EN149, EN14683 and CWA 17553 use pressure drop measurement systems, whereas here we implemented a back pressure measurement system. This makes direct comparison back to an individual standard challenging, however we can use this test setup to benchmark against commercially-available masks that fulfill their respective minimum technical standards for breathability.



(a) (b)

Fig. 2. (a) Cross-section schematic diagram of the back pressure test rig developed to benchmark breathability performance of different mask materials. The thick black line shows the 3D printed pressure chamber, the red line shows the foam sealant which when used with the rigid sealing ring creates an air-tight connection between the pressure chamber and the material under test. (b) Shows a photograph of the hardware.

These tests were performed on a range of commercially-available CFCs, medical face masks and flat-folding and cup-shaped FFRs. In total, ten different types of masks were tested. These are shown in Table 3.

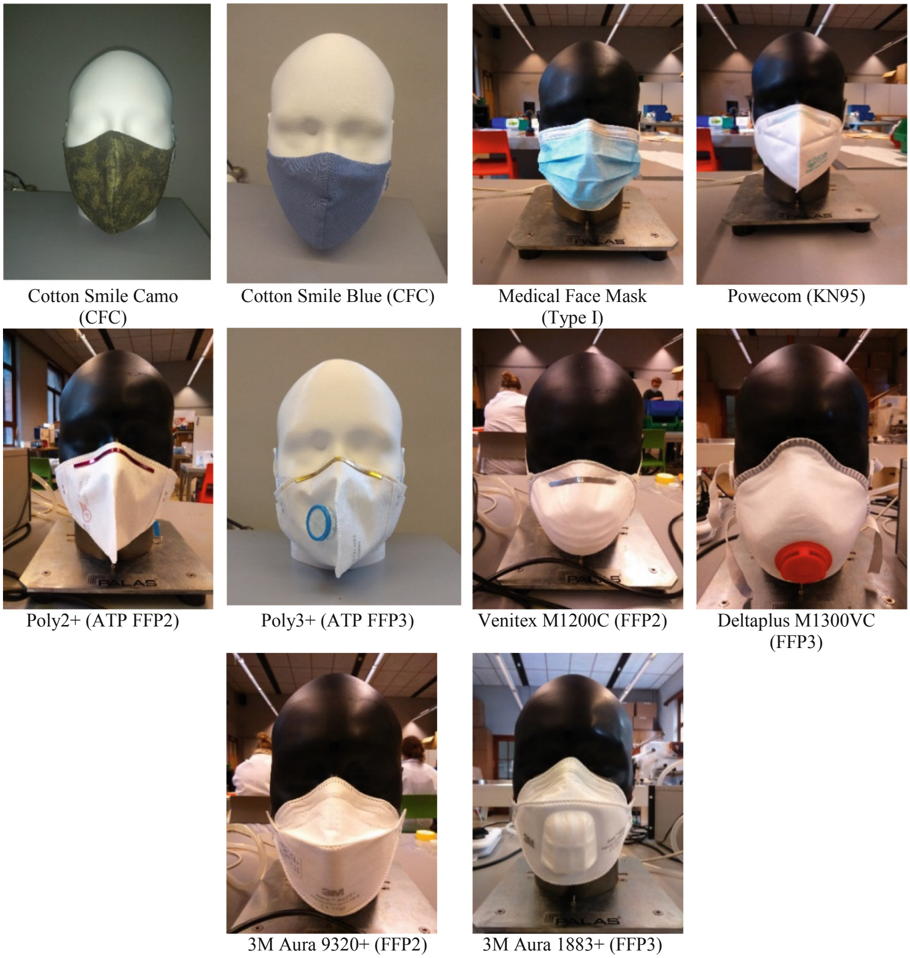


Fig. 3. Ten different community face coverings, medical face masks and filtering facepiece respirators tested in this study

4 Results

Ten masks were tested here, with a CFC-type mask tested with commercially-available activated carbon filter inserts. The values for PFE TIL are measured in percentage. The breathability is measured in Pascal. The results are shown in Table 4.

In the PFE the percentage of the “Cotton Smile camo” and the “Cotton Smile blue”, both community face covering, is very low (11.6% and 2.6%, respectively). But when an activate carbon filter is inserted in the community face covering, the PFE increases (98.7% and 97.3%) and it could pass the PFE FFP2 criteria. The PFE from “Surgical mask S1” is lower than the PFE from the community masks with filter. Most of the FFRs passes the PFE test.

Table 4. Comparison of masks under test, their technical standard and class, and PFE, TIL and breathability.

Mask Model	Standard	Class	PFE (%)	TIL (%)	Breathability (Pa)
Cotton Smile camo	CWA 17553	–	11.6	92.5	34
Cotton Smile camo + PM2.5 filter	CWA 17553	–	98.7	86.1	146
Cotton Smile blue	CWA 17553	–	2.6	92.5	20
Cotton Smile blue + PM2.5 filter	CWA 17553	–	97.3	86.3	127
Medical face mask	EN14683	Type I	78.6	83.8	78
Powecom	GB2626-2006	KN95	95.5	71.3	76
Antwerp Design Factory Poly2+	Belgian ATP	FFP2/FFP3	97.3	24.1	129
Venitex M1200C FFP2	EN149	FFP2	96.8	92.1	102
3M Aura 9320+	EN149	FFP2	99.7	19.8	91
Antwerp Design Factory Poly3+	Belgian ATP	FFP2/FFP3	97.0	29.4	118
Deltaplus M1300VC	EN149	FFP3	98.9	74.3	172
3M Aura 1883+	EN149	FFP3	99.9	17.0	126

In the TIL none of the masks passes their according criteria. The FFP2 criteria needs to be at less than 8%. However, the use of a rigid Sheffield headform for TIL measurements is difficult because the smooth surface between the mask and the headform is an unrealistic comparison for a human headform with bone, muscle and skin. Researcher from NIOSH demonstrated an advanced static headform with silicone polymer skin which overcame this limitation [1], however, the data measured here can still be used to compare between masks and use the good-fitting 3M Aura series respirators [7] as a benchmark. Between the FFRs, the "Venitex M1200C FFP2" and the "Deltaplus M1300VC FFP3" masks have one of the worst TIL value. Both of the masks have a cup style shape. The community face covering have a high TIL value even with the filter material.

The value of the breathability increases when the PFE increases. The pressure to breathe in the community masks with filter are slightly higher than that of the FFP2 respirators. The "Venitex M1200C FFP2" and "3M Aura 9320+ FFP2" masks have a PFE of 96.8 and 99.7 % respectively. The value is comparable with that of the community face coverings with filter that have a PFE of 98.7% and 97.3%. However, the "Venitex M1200C FFP2" and "3M Aura 9320+ FFP2" respirators have a breathability of 102 Pa and 91 Pa respectively. The community face coverings with filter have a breathability of 146 Pa and 127 Pa which is higher and thus more difficult to breathe through.

5 Conclusion

Community masks right now do not meet the CWA 17553 requirements. Mainly because of the PFE. The PFE value of the community masks are too low compared to the 70% level mask requirement. A solution for this problem is to insert a filter with a higher PFE in the community mask. This increases the PFE of the community face mask. With the filter it meets the level 90% CWA 17553 mask requirement and even the EN149 FFP2 PFE requirement. In this case the breathability was slightly higher than the FFP2 masks, but these values can only be used as an experimental comparison. Further tests with a more consistent and reliable method must be performed. The TIL is not a requirement for the CWA 17553 but it is nonetheless an important factor. Between the masks that have been tested, the community masks have one of the highest leakages even with the filter. This is a problem because a high TIL means that the air and particles could avoid the mask/filter barrier to enter the ambient environment. The risk of particles entering behind the mask is high.

Acknowledgements. This research was funded by Industrial Research Fund (IOF) of the University of Antwerp, grant number FFI200119.

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