CURRICULUM VITAE

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Assistant Professor, Department of Fashion Technology, National Institute of Fashion Technology, Panchkula, India
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Academic Qualifications – Ph. D. (Textile Engineering), M.Tech. (Textile Engg & Management), B.Tech (Textile Engineering)

Working Experience: 10 years of industrial, research, and academic experience in the field of Textile.

- Assistant Professor (Fashion Technology), at National Institute of Fashion Technology, Panchkula, India (Oct 2021 to Till date).
- Assistant Professor (Textile), Uttar Pradesh Textile Technology Institute, Kanpur, India (Sep 2018 to Sep 2021).
- Sr. Executive (QA), RSWM LTD, Bhilwara, Rajasthan, India (April 2016-Aug 2018)
- Assistant Executive (R&D), Vardhman Yarns and Threads Ltd., Hoshiarpur, Punjab, India (July 2015-April 2016).
- Nahar Spinning Mills Ltd. Mandideep, Madhya Pradesh, India (June 2012-July 2013).

List of Research Projects

- Development of Protective Clothing for Works Men of Transport Industries" under a collaboration research scheme sponsored by the National Project Implementation Unit India.
- Institute consultancy projects for MSME sponsored by UPTTI, Kanpur, India.

Member Ships – *Life member (L562), Asian Polymer Association: New Delhi, Delhi, IN*

- *Life member (L562), Thriving Engineers Alumni of Mlvtec, Bhilwara, India*

Edited Books and Chapters

- **Akhtarul Islam Amjad**, 2023, Self-Cleaning Nanofinishes and Applications, in: Handbook of Nanofibers and Nanocomposites Characteristics, Synthesis, and Applications in Textiles, Jenny Stanford Publishing https://doi.org/10.1201/9781003432746
- **Amjad, A.I.,** Regar, M.L., 2023. Fabric preparatory, in: Textile Calculation. Elsevier, pp. 171–195. https://doi.org/10.1016/B978-0-323-99041-7.00005-9
- **Amjad, A.I.**, Regar, M.L., 2023. Fabric preparatory, in: Textile Calculation. Elsevier, pp. 171–195. https://doi.org/10.1016/B978-0-323-99041-7.00005-9
- Meena, C.R., Hada, J.S., Regar, M.L., **Amjad, A.I.,** 2023. Fabric testing, in: Textile Calculation. Elsevier, pp. 349–368. https://doi.org/10.1016/B978-0-323-99041-7.00006-0
- Edited book on "Sustainable Growth in Textile", International Conference proceeding, 2021, 978-1685632458

Publication in International Journals

1. **Akhtarul Islam Amjad**. "Bamboo fibre: a sustainable solution for textile manufacturing." Advances in Bamboo Science (2024): 100088. https://doi.org/10.1016/j.bamboo.2024.100088
2. Mohd. Vaseem, Amandeep Singh Grover, **Akhtarul Islam Amjad**, " New Car price prediction model using AI before launch: Forward selection Regression" International Journal of Computer Sciences and Engineering, Vol.11, Issue.01, pp.49-55, 2023.
3. Akhtarul Islam Amjad & Rajiv Kumar, Effect of Eco-friendly Bamboo Rayon, Lyocell, and Seacell Fibres on the Properties of Blended Knitted Melange Fabrics. Fibers Polym (2023). https://doi.org/10.1007/s12221-023-00148-1
4. Akhtarul Islam Amjad & Rajiv Kumar (2022) Sustainable Production and Performance Analysis of Cotton Melange Fabrics, Journal of Natural Fibers, DOI: 10.1080/15440478.2022.2044963
5. Madan Lal Regar, **Akhtarul Islam Amjad.** Effect of Solvent Treatment on Siro and Ring Spun TFO Polyester Yarn. *Tekstilec, 2021, Vol. 64(1), 47–54* DOI: 10.14502/Tekstilec2021.64.47-54
6. Madan Lal Regar, **Akhtarul Islam Amjad,** and Atiki Singhal, Camouflage Fabric – Fabric for Today's Competitive Era, 2020 / Volume 3 / Issue 4 / Pages 186-201
7. **Amjad, A.I.,** Kumar, R. Effect of Fibre Fineness and Noil Extraction on the Different Shade Depths of Melange Yarns. J. Inst. Eng. India Ser. E 101, 33–43 (2020). https://doi.org/10.1007/s40034-019-00155-z
8. **Amjad, A.I.,** Kumar, R Evaluation of Mechanical and Physical Characteristics of Eco blended Melange YarnsTekstilec, 2020, 63(2), 94-103 DOI: 10.14502/Tekstilec2020.63.94-103
9. Madan Lal Regar, **Akhtarul Islam Amjad,** and Niharika Aikat. "Studies on The Properties of Ring And Compact Spun Melange Yarn." *Internation Journal of Advance Research And Innovative Ideas In Education,* 2017 3(2), p. 476-484. DUI: 16.0415/IJARIIE-4082
10. Madan Lal Regar, **Akhtarul Islam Amjad.** Basalt Fibre – Ancient Mineral Fibre for Green and Sustainable Development. *Tekstilec*, 2016, 59(4), p. 321−334. doi: 10.14502/Tekstilec2016.59.321-334.

International and National Conference Publications

1. **Akhtarul Islam Amjad**, Mohd. Vaseem, Optimization of complex product for warranty: a software of warranty, International Conference on Scientific Research, 26-28 April 2024, Kırşehir Ahi Evran University, Kırşehir, Türkiy
2. Anita Chahal, **Akhtarul Islam Amjad,** The child psychology and clothing in iranian cinema: abbas kiarostami's 'where is the friend's home' International Conference on Scientific Research, 26-28 April 2024, Kırşehir Ahi Evran University, Kırşehir, Türkiy
3. **Akhtarul Islam Amjad,** Mohd. Vaseem, Nikita, Marketing of Fashion with the Help of Sustainability, 3rd International Architectural Sciences and Applications Symposium, September 14-15, 2023, Naples, Italy
4. **Akhtarul Islam Amjad**, Amandeep Grover, Mohd Vaseem, New Car price prediction model using AI before launch: Forward selection Regression, NATIONAL CONFER. RESEARCH, JIS University, Agarpara, Kolkata (West Bengal) Date:23/06/2023

5. **Akhtarul Islam Amjad**, Sustainable approaches for the textile manufacturing, AHI EVRAN 3rd INTERNATIO, Institute Of Economic Development And Social Researches IKSAD, Azerbaijan Turkey,03/03/2023
6. **Akhtarul Islam Amjad**, Rajiv Kumar, Concept for the development of sustainable textile products, International conference on sustainable growth in textile (SGT, 2021), 19 to 21 Aug, 2021 at UPTTI, Kanpur.
7. Mohini Katiyar, **A. I Amjad**, “Textile showing self-cleaning activity under day light irridation”, International conference on sustainable growth in textile (SGT, 2021), 19 to 21 Aug, 2021 at UPTTI, Kanpur.
8. Priya, Akanksha, **A. I Amjad**, “Indian consumer perception in Green apparels”, International conference on sustainable growth in textile (SGT, 2021), 19 to 21 Aug, 2021 at UPTTI, Kanpur.
9. Nirbhay Beri, Gaurav Sharma, **A. I Amjad**, Sufia Azim “Review on alovera gel as new thickening material”, International conference on sustainable growth in textile (SGT, 2021), 19 to 21 Aug, 2021 at UPTTI, Kanpur.
10. Saumya Gupta, Tithi Gupta, **A. I Amjad**, Sufia Azim “Review on electrical conductive textile by screen printing”, International conference on sustainable growth in textile (SGT, 2021), 19 to 21 Aug, 2021 at UPTTI, Kanpur.
11. **Akhtarul Islam Amjad**, Rajiv Kumar, Unique appearances and developments in melange yarn, International conference on advances in textile, fashion and craft (ATFC, 2021), 22 to 24 March, 2021 at UPTTI, Kanpur
12. **Akhtarul Islam Amjad,** Rajiv Kumar, Eco-friendly functional fibre for melange yarn production, National conference on sustainable growth in textile (NCSGT,2020), 12 to 14 Aug 2020 at UPTTI
13. Madan Lal Regar, **A I Amjad,** Disha Verma, Shruti Upadhyay, Sonal Sahu, Akash Patel Sustainability in textiles, National conference on sustainable growth in textile (NCSGT,2020), 12 to 14 Aug 2020 at UPTTI Kanpur, India
14. M L Regar, **A I Amjad,** M Uttam, Garima Pal, Sapna Giri, Priyanshi Gupta Aakriti **Yadav**, Recent development in medical textile, National conference on sustainable growth in textile (NCSGT,2020), 12 to 14 Aug,2020 at UPTTI Kanpur, India,
15. **A I Amjad,** Madan Lal Regar, Alka Ali, S.K. Rajput, Tariq Khan, Advance in textile chemical processing, National conference on sustainable growth in textile (NCSGT,2020), 12 to 14 Aug 2020 at UPTTI Kanpur, India
16. **Akhtarul Islam Amjad**, Rajiv Kumar, Aesthetic And Moisture-Transportation Properties Of Blended Melange Yarns, International Conference on Handlooms, Fashion, Non-woven and Technical Textiles (ICHFNTT 2020) on 27th and 28th February 2020 at Department of Textile Technology, University College of Technology, Osmania University, Hyderabad, India.
17. Sushmita Mukherjee, Madan Lal Regar & **A I Amjad,** Dyeing From The Waste Of Black Tea: A Socio-Economic Approach, International Conference on Handlooms, Fashion, Non-woven and Technical Textiles (ICHFNTT 2020) on 27th and 28th February 2020 at Department of Textile Technology, University College of Technology, Osmania University, Hyderabad, India.
18. Madan Lal Regar, **A I Amjad**, M Uttam, Surbhi Mishra, Satyam Jha, Shashi, Self Healing Fibre Reinforcement Composite, International Conference on Handlooms, Fashion, Non-woven and Technical Textiles (ICHFNTT 2020) on 27th and 28th February 2020 at Department of Textile Technology, University College of Technology, Osmania University, Hyderabad, India.
19. M L Regar, **A I Amjad**, M K Singh, Garima Pal, Srishti Agrawal, Priyanshi Gupta, Camouflage Fabric- Fabric For Today’s Competitive Era, International Conference on

Handlooms, Fashion, Non-woven and Technical Textiles (ICHFNTT 2020) on 27th and 28th February 2020 at Department of Textile Technology, University College of Technology, Osmania University, Hyderabad, India.

20. M L Regar, **A I Amjad,** Anuj Kapoor, Aman Sachan, Fabric From Plastic Waste, International Conference on Handlooms, Fashion, Non-woven and Technical Textiles (ICHFNTT 2020) on 27th and 28th February 2020 at Department of Textile Technology, University College of Technology, Osmania University, Hyderabad, India.
21. **Akhtarul Islam Amjad**, Rajiv Kumar, MELANGE YARN MANUFACTURING, PROPERTIES, DEVELOPMENTS AND APPLICATIONS, Advances in Textile Material and Processes (ATMP-2019) on 2^{nd} – 3^{rd} December 2019 at UPTTI, Kanpur, India, India.
22. Mansi Gupta, Neha Gond, Vedant Tripathi, Deeksha Mishra, Shubham Joshi, A**.I. Amjad,** Mukesh Kumar Singh, Monitoring Cardiac and Respiration Activity Using Fiber Bragg –Grating-Based Sensor, Conference on Recent Advance in Polymer Technology (RAPT2020) on Jan 31^{st} –Feb 1^{st}, 2020 at University Institute of Chemical Technology, KBCNMU, Jalgaon, India.
23. Madan Lal Regar, **A I Amjad**, Sufia Azim, Utkarsh Aggarwal, Shubhanshu Singh, Shikha Maurya, Nanofiber- A New Fibre Production Technology, Conference on Recent Advance in Polymer Technology (RAPT2020) on Jan 31^{st} –Feb 1^{st}, 2020 at University Institute of Chemical Technology, KBCNMU, Jalgaon, India.
24. Madan Lal Regar, **A I Amjad**, M Uttam, Aarav Agnihotri, Antra Gupta, Savita Yadav, Electrical Conductive Textiles using Conductive ink, Conference on Recent Advance in Polymer Technology (RAPT2020) on Jan 31^{st} –Feb 1^{st}, 2020 at University Institute of Chemical Technology, KBCNMU, Jalgaon, India.
25. Madan Lal Regar, **A I Amjad,** Alka Ali, Nirbhay Beri, Gaurav Sharma, Md. Kaif Salim, Production of Anti UV Textile Coloration from Peanut Red Skin, Conference on Recent Advance in Polymer Technology (RAPT2020) on Jan 31^{st} –Feb 1^{st}, 2020 at University Institute of Chemical Technology, KBCNMU, Jalgaon, India.
26. Madan Lal Regar, **A I Amjad,** S Azim, Mariyam Khanam, Akshat, Aayush Rathore, Utilization of Non-Degradable Waste- From Trash to Treasure, Conference on Recent Advance in Polymer Technology (RAPT2020) on Jan 31^{st} –Feb 1^{st}, 2020 at University Institute of Chemical Technology, KBCNMU, Jalgaon, India.
27. M L Regar, **A I Amjad,** Sufia Azim, Taha, Anuj Kapoor, Ishika Rajvanshi, Aman Sachan, A Sustainable Approach to Dye Fabric with Flowers, Conference on Recent Advance in Polymer Technology (RAPT2020) on Jan 31^{st} –Feb 1^{st}, 2020 at University Institute of Chemical Technology, KBCNMU, Jalgaon, India.
28. **Akhtarul Islam Amjad,** Rajiv Kumar, Madan Lal Regar, Synthetic Sweat Transportation through Cotton Melange Yarns, Conference on Recent Advance in Polymer Technology (RAPT2020) on Jan 31^{st} –Feb 1^{st}, 2020 at University Institute of Chemical Technology, KBCNMU, Jalgaon, India.
29. Madan Lal Regar, **A I Amjad,** Priyanshi Gupta, Garima Pal, Divya Dixit, CONDUCTIVE FABRIC PREPARATION BY GRAPHENE OXIDE, Advances in Textile Material and Processes (ATMP-2019) on 2^{nd} – 3^{rd} December, 2019 at UPTTI, Kanpur, India, India.
30. Madan Lal Regar, **A I Amjad**, M Uttam, Prateek Gupta, Rahul Lodhi, OIL AND STAIN RESIST FABRICS, Advances in Textile Material and Processes (ATMP-2019) on2^{nd} – 3^{rd} December 2019 at UPTTI, Kanpur, India, India.

31. **A I Amjad**, Madan Lal Regar, Disha Verma, Shivani Tyagi, FUTURE FABRICS- A NEW AGE OF CLOTHING, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.
32. **Akhtarul Islam Amjad**, Madan Lal Regar, Aditya Krishna, Sikandar Prajapati, PROPERTIES of DUAL CORE LYCRA YARN, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
33. M L Regar, **A I Amjad**, Pramod Kumar, Srishti Agrawal, Sapana Giri, Aakriti Yadav, EFFECT OF FIBER ON APPAREL QUALITY, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
34. Madan Lal Regar, **A I Amjad**, Jaya Sharma, Piyush Mishra, Anushka, CONVEYOR BELTS- A FLEXIBLE COMPOSITE, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
35. Madan Lal Regar, **A I Amjad**, Jaya Sharma, Rajeev Kumar Gautam, Shivansh Awasthi, APPLICATIONS OF NATURAL FIBER IN REINFORCED COMPOSITES, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
36. Madan Lal Regar, **A I Amjad**, J P Singh, Saurabh Mishra, WATsun: WATER PURIFIER, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
37. **A I Amjad**, Madan Lal Regar, Shivam Tiwari, Aditya Mishra, EVALUATION OF MOISTURE TRANSPORTATION BEHAVIOUR OF TEXTILE MATERIALS, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
38. Madan Lal Regar, **A I Amjad**, Abha Bhargava, Sushmita Mukherjee, WASTE OF BLACK TEA – A SUSTAINABLE WAY FOR DYEING, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
39. Madan Lal Regar, **A I Amjad**, Mahendra Uttam Ayushi Garg, Nidhi Mishra, SELF COOLING FABRIC: A NEW INNOVATION, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
40. Madan Lal Regar, **A I Amjad**, Sufia Azim, Sakshi Chaudhary, RECYCLING AND REUSING APPROACHES OF TEXTILE PRODUCTS, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
41. Madan Lal Regar, **A I Amjad**, Asha, Vaishali Singh, Saurabh Verma, SMART SENSOR FABRIC by ELECTRONIC TEXTILE**,** Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December, 2019 at UPTTI, Kanpur, India, India.
42. **A I Amjad**, M L Regar, J P Singh, NirbhayBeri, Gaurav Sharma, USE OF PEANUT RED SKIN TO PRODUCE ANTI-UV TEXTILE COLORATION, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.
43. **A I Amjad**, Madan Lal Regar, Shivam Tiwari, Aditya Mishra, Evaluation of moisture transportation behavior of textile materials, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.
44. **A I Amjad**, Madan Lal Regar, Taha, Anuj Kapoor, Ishika Rajvanshi, Aman Sachan, Dyeing from floral waste, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.
45. **A I Amjad**, Madan Lal Regar, Manya Jain, Surbhi Mishra, Satyam Jha, Self-healing fiber rein enforcement composite, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.

46. M L Regar, **A I Amjad,** J P Singh, Somitra Yadav, Vaibhav Singh Panwar, Decline of Textile Industries In India, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.
47. **A I Amjad**, Madan Lal Regar, Alka Ali, Tariq Khan, BANANA FIBRE, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.
48. **A I Amjad**, Madan Lal Regar, Mukesh Kumar Singh, Aarav Agnihotri, Antra Gupta, Flexible Shielding for electromagnetic Rays, Advances in Textile Material and Processes (ATMP-2019) on 2nd – 3rd December 2019 at UPTTI, Kanpur, India, India.
49. **Akhtarul Islam Amjad** & Rajiv Kumar, Properties of Sustainable Cotton Melange Yarns, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
50. **A I Amjad**, M L Regar and Sushmita Mukherjee, Dyeing from Waste of Tea Shops, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
51. Madan Lal Regar, **A I Amjad**, J P Singh, Shivam Kumar Tiwari and Ajeet Kumar, Chemical Protective Clothing, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
52. **A I Amjad**, Madan Lal Regar, M K Singh, Aarav Agnihotri, Mohit Dinkar and Saurabh Maliyan, Structure and Properties of Healthcare and Hygiene Product, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
53. Madan Lal Regar, **A I Amjad**, Prashant Vishnoi, Hamza Faisal, Mohit Jaiswal and Anmol Singh, Ballistic Armour – Protective Clothing, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
54. M L Regar, **A I Amjad**, Mahendra Uttam, Astha Singh and Shrasti Rajouria, Agro Textile – A Need of Farmer, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
55. Tariq Khan, M L Regar, **A I Amjad** and Alka Ali, Colour Fast Finish: A Eco – friendly Process, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
56. Madan Lal Regar, **A I Amjad**, Ali Usama and Gauri Dubey, Electromagnetic Shielding Fabrics – Wearable Textile, International Conference Emerging Trends in Traditional & Technical Textiles (ICETT 2019) on 1st – 3rd November 2019 at Department of Textile Technology, Dr. B.R. Ambedkar NIT, Jalandhar, India, ISBN: 978-93-5382-111-1.
57. **Akhtarul Islam Amjad,** Rajiv Kumar, Properties of sustainable melange yarn, International Conference on Emerging Trends in Traditional and Technical Textiles on 01-03 November 2019, NIT, Jalandhar.

58. Madan Lal Regar, **Akhtarul Islam Amjad,** Effect of strain on the conductivity of high Lycra yarn fabric, *International Conference on Advances in Polymeric Materials & Human Healthcare* on 16-18 October 2019, Goa, India.
59. **Akhtarul Islam Amjad,** Madan Lal Regar, Filter efficacy of bamboo charcoal polyester non-woven fabric, *International Conference on Advances in Polymeric Materials & Human Healthcare* on 16-18 October 2019, Goa, India.
60. Madan Lal Regar, Deeksha Mishra, **Akhtarul I. Amjad,** Rohit Singh, A Review on Geotextile, *58th Joint Technological Conference & Tech-Tex: A Conference on Protective & Automotive Textiles* on 15th-16th Feb. 2019 at Northern India Textile Research Association(NITRA) Ghaziabad (U.P), India.
61. Deeksha Mishra, **Akhtarul I. Amjad** and Madan Lal Regar, Development & Designing of Carpets on Handlooms, *58th Joint Technological Conference & Tech-Tex: A Conference on Protective & Automotive Textiles* on 15th-16th Feb. 2019 at Northern India Textile Research Association(NITRA) Ghaziabad (U.P), India.
62. Madan Lal Regar, **A.I. Amjad** and S. K. Sinha, Role of Porosity in Textile Material, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
63. *M.L. Regar*, **A.I. Amjad,** Sakshi Chaudhary, and Aniket Yadav, Self-cleaning Fabric Production by Nanotechnology, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
64. **Akhtarul Islam Amjad,** Madan Lal Regar, Tariq Khan, and Paurush Bansal, A Review on Natural and Artificial Spinning of Silk, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
65. **A.I. Amjad,** Madan Lal Regar, Astha Shukla, and Chitranshu Singh, Lean Manufacturing in Textile, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
66. Madan Lal Regar, **A.I. Amjad,** Sufiya Azim, Pradeep and Rajnath Mishra, Pashmina—A Luxury Fibre, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
67. Madan Lal Regar**, A.I. Amjad,** Subhankar Maity, Sakshi Chaudhary and Sharmistha Singh, Oil Absorbent Textile, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
68. **Akhtarul I. Amjad,** Madan Lal Regar, Subhankar Maity, Vikas Kumar Verma and Jahnvi Yadav, A Review on Properties of Basalt Fibre in Compare to High-Performance Fibres, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
69. **Akhtarul I. Amjad,** Rohit Kumar, and Madan Lal Regar, Bamboo and Banana Fibre Excellent Material for Fibre Reinforced Composite, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
70. Mukesh Kumar Singh, M.L. Regar, **A.I. Amjad,** Nishtha Singh, Mahima Rathore and Sweta Tripathi, Cosmetotextiles, *International Conference on Advances in Textile*

Materials and Processes (ATMP-2018) on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.

71. Alka Ali, M.L. Regar, **Akhtarul I. Amjad,** Shubham Kumar Pandey, Shivani and Aman Pandey, Microencapsulation in Textiles, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
72. Prashant Vishnoi**, A.I. Amjad,** Madan Lal Regar, Shivangini Rai and Jigyasa Hemji, Traditional Approaches for New Era Fashion, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November, 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
73. Rahul Kumar Shringirishi, A.K. Patra, **Akhtarul I. Amjad,** and M.L. Regar, A Review on Antimicrobial Finishes on Cotton Fabric by Various Natural Extracts, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November, 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
74. Deeksha Mishra**, Akhtarul I. Amjad,** and Madan Lal Regar, Carpet Designing on Handlooms, *International Conference on Advances in Textile Materials and Processes (ATMP-2018)* on 19-20 November 2018 at UPTTI Kanpur, India in association with IIT-Kanpur, India, India.
75. Akhtarul Islam Amjad and **Ravi Jain**, Pashmina- The Diamond Fibre, *International Conference on Technical Textiles and Nonwovens, 2014*, held at IIT, Delhi, India.

Expert Lecture

- Delivered an Expert Lecture in the national workshop on Effective Technical Communication at UPTTI Kanpur, India.
- Delivered an Expert Lecture for pre-PhD coursework at DG PG College, Kanpur, India.

Organized Workshop/Seminar/Summit/Webinar/Meet

- Convenor of International conference International E-conference on sustainable growth in textile (SGT-2021) organized on 19-21 Sep 2021 at UPTTI, Kanpur, India.
- Convenor of national conference NCSGT 2020 organized on 12-14 Aug 2020 at UPTTI, Kanpur, India.
- One-week Industrial visit on Recent Trends in Textile Industry in the capacity of **Convenor** from 20th February 2020 to 24th February 2020 at Baddi and Kullu.
- One-week Workshop on Entrepreneurship as a career option- IIC week in the capacity of **Convenor** from 26th December 2019 to 31st December 2019 at UPTTI Kanpur, India.
- One week Workshop on Start-up & Entrepreneurship in the capacity of **Convenor** from 23rd September, 2019 to 28th September, 2019 at UPTTI Kanpur, India.
- Smart Textile Hackathon 2019 in the capacity of Convenor from 27th September, 2019 to 28th September, 2019 at UPTTI Kanpur, India
- 1-day workshop on *Effective Technical Communication* in the capacity of **convenor** on 22nd Aug 2019 at UPTTI Kanpur, India.
- Organized Viraksha Ropan Maha Kumbh (*Election Pattern- 2019)* in the capacity of **Coordinator** on 8th Aug 2019 at UPTTI Kanpur, India
- Organized Tree Plantation Drive (*Van Mahotsav- 2019)* in the capacity of **Coordinator** on 6th July, 2019 at UPTTI Kanpur, India
- Organized Tree Plantation Derive (*Van Mahotsav- 2019)* in the capacity of **Coordinator** on 6th July, 2019 at UPTTI Kanpur, India

- Organized Technical Fest (*Texup 2019)* in the capacity of **convenor** on 2nd March, 2019 at UPTTI Kanpur, India.
- Competition and Workshop on *Paint your idea* in the capacity of **convenor** on 28th Feb, 2019 at UPTTI Kanpur, India.
- 1 days workshop on *orientation on entrepreneurship as a career option* in the capacity of **convenor** on 29th Jan, 2019 at UPTTI Kanpur, India.
- Summit on *Youth Technologist Startup Conclave 2019* in the capacity of **organizing secretary** on 22nd Jan, 2019 at UICT Jalgaon in collaboration with UPTTI Kanpur, India.
- Faculty-student Industrial Visit on 23rd Jan, 2019 at Raymond Jalgaon.
- Workshop on *Sustainability in Textile Chemical processing* in the capacity of **convenor** on 11th & 12th Jan, 2019 at UPTTI Kanpur, India.
- Workshop on *IPR for students and Faculty members* in the capacity of **convenor** on 10th Jan, 2019 at UPTTI Kanpur, India.
- A Webinar on *India's first leadership talk* in the capacity of **convenor** on 1st and 3rd Oct, 2018 at UPTTI Kanpur, India.
- Summit on *Young Innovators Summit 2018* in the capacity of **Program Coordinator** on 23rd Oct, 2018 at UPTTI Kanpur, India in collaboration with UICT Jalgaon.
- 2 days' workshop on *Communication and personality development* in the capacity of **organizing secretary** on 1st and 3rd Oct, 2018 at UPTTI Kanpur, India.

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Sustainable Production and Performance Analysis of Cotton Melange Fabrics

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ABSTRACT

Sustainability issues are gaining momentum in the apparel and textile industries. The use of sustainable raw material, process and recycling are basic approaches for developing the sustainable manufacturing and products of textile. In this study, sustainable fabrics that can fulfil the environmental, economic, and social responsibilities are developed and performances are assessed. Organic cotton fiber, Global Organic Textile Standard (GOTS) approved dyes, and RO treated recycled water are used to manufacture different quality sustainable melange yarns and fabrics. Apart from the novelty in the raw material and manufacturing, Box Behnken experimental design was also incorporated for three factors such as fineness of fiber, noil extraction%, and shade depth%. The use of recycled water and biodegradable raw materials leads to environmental and ecological advantages. In terms of technical performance, fineness, and noil extraction have a significant impact on dimensional, mechanical, and physical properties such as stitch density, areal density, thickness, porosity, bursting strength and abrasion resistance of cotton melange knitted fabrics. Shade depth also considerably affects all the above properties of fabrics except thickness, density, and porosity. Higher areal density, lower thickness, and lower porosity of cotton melange fabric with the high extraction of noil and low value of fiber fineness are found.

摘要

在服装和纺织行业, 可持续性问题的势头越来越大. 使用可持续的原材料, 加工和回收是发展可持续的纺织制造和产品的基本途径. 在这项研究中, 开发了能够履行环境, 经济和社会责任的可持续织物, 并对其性能进行了评估. 有机棉纤维, 全球有机纺织标准 (GOTS) 批准的染料和RO处理的循环水用于制造不同质量的可持续混合纱和织物. 除了原材料和制造方面的新颖性外, 实验设计还包括三个因素, 如纤维细度, 落麻提取率和阴影深度%. 循环水和可生物降解原材料的使用带来了环境和生态优势. 就技术性能而言, 细度和落棉提取率对混棉针织物的尺寸, 机械和物理性能 (如针迹密度, 面密度, 厚度, 孔隙率, 耐破强度和耐磨性) 有显著影响. 除厚度, 密度和孔隙率外, 阴影深度也会显著影响织物的上述所有性能. 落麻提取率高, 纤维细度值低的棉混纺织物, 其面密度高, 厚度低, 孔隙率低.

关键词
织物性能; 混杂纱; 有机纺织品; 可持续面料; 阴影深度

KEYWORDS
Fabric properties; melange yarn; organic textile; sustainable fabrics; shade depth

Introduction

In terms of economic activities, the growth of the global textile market is predicted to reach USD 1350.2 billion by 2027, from USD 920 billion in 2018 (Textile Market Size 2021 – 2028). However, being a rewarding market on one end, the textile industry is like a double-edged sword due to rising concerns about the harmful environmental impacts. These concerns require a high level of monitoring to flourish ecosystems for developing sustainable products (Leonas 2017; Liu et al. 2019). Responding to

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human needs without overcoming or disturbing nature or culture is called sustainability (Muthu et al. 2012). In current years, sustainability has become a major requirement in textile manufacturing and developments at a very rapid pace (Leonas 2017). The demands of consumers are increasing for ecologically and socially acceptable products. Sustainable textile has identified the triple bottom line which consists of three basic pillars of Profit (economic), People (social), and Planet (environment) (Purvis, Mao, and Robinson 2019).

Manufacturing of cloth is a long conversion process from fiber, yarn, fabric to garment. In this process, several unsustainable approaches like the use of harmful chemicals, non-biodegradable raw material, high consumption of water and energy, discharge of hazardous chemicals, effluent, and use of non-biodegradable packaging materials create the issue for sustainable textiles and clothing (Eryuruk 2012). These issues can be eliminated by a systematic approach to shift the production process toward a clean production process. Fiber is a basic component of any textile material. Cotton fiber is vastly used textile fiber for clothing but during the cultivation of cotton, the use of large amounts of pesticides, insecticides, and water make it less sustainable. Organic cotton may be a promising tool to resolve all environmental problems associated with textile industries (Islam, Khan, and Khalil 2015). Similarly, gray yarn made from sustainable raw material may fulfil the need of two aspects such as planet (environment) and people (social) but a low margin of profit. This can make it less suitable for the third aspect (profit). Value-added fancy yarn may be the option for the limitation of the third aspect. Thus, a value-added textile product which is using environmentally friendly biodegradable raw material (fiber, chemicals, dyes etc.) and fulfilling the social requirements may be called sustainable textile products (Arya et al. 2014; Kooistra, Termorshuizen, and Pyburn 2006).

Melange yarn is a fancy yarn, made from two or more fiber groups with different colors or dye affinities and is known for its attractive color and appearance (Ray, Ghosh, and Banerjee 2018). Melange yarn is an example of manipulation of fiber characteristics. Mixing of fibers with different colors could be done either in the blow room at the start of spinning preparation or by feeding differently dyed fibers to the draw frame (Regar, Amjad, and Aikat 2017). The wavy-like effect and a wide range of color tones due to different colored fibers blending makes it much popular and rich in look (Amjad and Kumar 2020). Textile products made of melange yarn have a certain ambiguous cyclical effect. Melange yarns are value-added yarns and are produced to get higher prices due to their esthetic values with unique color and fancy effect but the use of unsustainable raw materials, chemicals, and high effluent discharge make it less sustainable. Melange yarn produced from organic fibers along with global organic textile standards (GOTS) approved dyes may fit all three pillars of sustainability (Amjad and Kumar 2020; Wang et al. 2020).

Process parameters affect the quality and performance of melange yarns and fabrics. Apart from process parameters, the properties of raw materials also influence the quality of melange products. All textile technocrats want to produce a product of desired features to fulfil the requirements of the end-user (Memon, Khoso, and Memon 2015). Hence, awareness about the development and manipulation of fiber properties and effective translation of these properties into yarn and fabric properties are essential. Researchers have investigated that wet processing of cotton fibers cause, removal of wax, higher cohesion, greater entanglement, and decrease in fibers strength. Re-processing of the fibers leads to fiber damage and decreasing of their length and strength parameter. These variations on fibers not only affect the efficiency of the spinning process, but also the mechanical and physical properties of the final yarn and fabric (Amjad and Kumar 2020; Liu et al. 2019; Naik and Bhat 2008; Ray, Ghosh, and Banerjee 2018).

Some references are available regarding research work on the conventional approach of melange yarns and fabrics but very few references are available regarding the use of sustainable fibers and dyes for the production of yarns and fabrics. Hence, it was thought to study the sustainable melange fabrics and effective translation of the development in terms of technical performance.

Material and methods

Manufacturing sustainable fabric

The melange fabric samples of organic cotton were produced on a knitting machine by varying three different fineness of cotton, noil extraction%, and shade depth % during yarn manufacturing. Knitting machines used to prepare the samples for the study possess gauge 24, no. of feeder 4, and loop length 2.8. Combinations of gray and dyed fibers are used to manufacture the yarn and final fabric. All types of melange yarns and fabrics are produced at RSWM Ltd., India. To maintain the sustainability of the final product, apart from sustainable raw materials, global organic textile standards (GOTS) and Oeko-Tex approved dyes and chemicals are used. Recycled water is used for dyeing which is obtained after treating the wastewater with a series of physicochemical and biological processes and two stages reverse osmosis (RO) membrane systems. Water parameters are shown in Table 1.

For evaluation of the technical performance of the samples, Box–Behnken design is applied as the response surface methodology tool and a total of 15 fabric samples are produced according to design. The detailed experimental design in the study is given in Table 2 as coded variables. For the statistical analysis and significance, analysis of variance (ANOVA) is carried out with three factors and three levels.

Testing

After developing the sustainable fabric, the performance of the fabric is evaluated with the help of the physical and mechanical properties of the final fabric according to the standard procedures. The melange knitted fabrics were pre-treated to remove impurities, 1% anionic surfactant in 1 L of water is

Table 1. Recycled water characteristics.

Parameters	Inlet to ETP	Inlet to RO	RO permeate
pH	9.86	7.72	7.12
Total suspended solids (mg/L)	39	21	2
Total dissolved solids (mg/L)	6035	5938	253
BOD (mg/L)	218	350	8
COD (mg/L)	698	504	17
Total hardness (mg/L) as $CaCO_3$	248	258	5

Table 2. Box-Behnken design plan for cotton melange fabrics.

	Statistical Design Plan			Actual Design Plan		
Run	Fiber Fineness (Mic.)	Noil Extraction (%)	Shade Depth (%)	Fiber Fineness (Mic.)	Noil Extraction (%)	Shade Depth (%)
1	1	0	−1	4.6	11	20
2	0	1	1	4.2	21	70
3	−1	0	−1	3.8	11	20
4	0	0	0	4.2	11	45
5	0	0	0	4.2	11	45
6	0	−1	−1	4.2	0	20
7	−1	1	0	3.8	21	45
8	0	1	−1	4.2	21	20
9	1	1	0	4.6	21	45
10	0	0	0	4.2	11	45
11	1	0	1	4.6	11	70
12	0	−1	1	4.2	0	70
13	−1	0	1	3.8	11	70
14	−1	−1	0	3.8	0	45
15	1	−1	0	4.6	0	45

used. The treatment is carried out for 45 minutes at boiling temperature. After the treatment, the samples were thoroughly rinsed with water at neutral pH and then kept in a room for drying and conditioning at 20°±2°C and 65%±2% RH for 1 day.

Determination of dimensional properties

The course per centimeter and wales per centimeter (WPcm) are counted with the help of pick glass. Stitch density is the number of loops per unit area, which are calculated according to ASTM D 3887, by multiplying the number of wales and courses per unit length. The stitch density was calculated as follows:

Stitch density in cm^2 = Course per cm × Wales per cm

After relaxation and conditioning of knit fabric samples, the areal density of samples was tested according to ASTM D3776 test methods. Fabric thickness tests are carried out as per ASTM D 1777–96 knitted fabric thickness testing.

Determination of physical and mechanical properties

The overall porosity is defined as the ratio of open space to the total volume of the porous material and accordingly, it was calculated from the measured thickness and weight per unit area values using the following equations (Mukhopadhyay and Midha 2008):-

The porosity of all the fabrics was determined using the following formula:

$$\text{Fabric porosity\%} = 1 - \frac{Fabric\ density(g/cm^3)}{Fibre\ density(g/cm^3)} \text{x100}$$

Where

$$\text{Fabric density} = \frac{\text{Fabric GSM}}{\text{Fabric thickness in m}}$$

The bursting strength of each of the knitted fabrics was tested as per ASTM D3787–01. The bursting strength of the samples was measured by an automatic bursting strength tester. Samples are gradually set on the diaphragm, the automatic bursting strength tester, measures time, distortion, pressure, and the flow rate to burst the fabric.

The abrasion property was tested with the help of a Martindale abrasion tester according to EN ISO 12947 part 2 and part 3. Part 2: Determination of specimen breakdown, and Part 3: Determination of mass loss. Each specimen of 140 mm diameter was cut with a circle of standard from the fabric being tested. The fabric is mounted at the base platform and an abrader (woven worsted wool) is mounted at the top holder. A pressure of 12 Kpa is applied through a spindle which is inserted through the top plate. The endpoint is determined by the maximum revolution required to distort the first yarn or formation of a hole in the fabric specimen (Abdullah et al. 2006).

Specimen mass loss was determined for a predetermined number of rubs. For cotton fabric, mass loss was determined at the following number of rubs: 1000, 5000, 25000, 50000, and 75000. Mass loss was determined for each test, to the nearest 1 mg from the difference between test specimen mass before testing and the mass after testing.

Pilling was measured as per the standard ISO 12945–2 and up to 7000 multi-directional rubbing cycles. There is a possibility of pouring pills according to the fiber and yarn structure at 5000 and 7000 cycles. In addition, pill formations may not be observed clearly at 125, 500 and 1000 cycles. It was kept in mind during the test. After each completed rubbing cycle the specimens were brought under sufficient light and compared to standard photographs and grading was done. Grade 5 is assigned if there is no change in fabric sample after rubbing, 4 is assigned for slight surface fuzzing and/or partially formed pills, 3 is assigned for moderate surface fuzzing and/or moderate pilling, in which pills of varying size and density partially covers the sample surface, 2 is assigned for distinct surface fuzzing and/or pilling, in which pills of varying size and density covers a large proportion of the sample, 1 is assigned for dense surface fuzzing and/or severe pilling, in which pills of varying size and density covers the whole of the specimen surface.

Results and discussion

For all sets of samples, results of mechanical and physical properties such as bursting strength, abrasion resistance, and pilling resistance are shown in Table 3.

Analysis of variance has been conducted for finding the significant impact of all three factors on the dimensional, mechanical, and physical properties (Table 4). Pilling grades are subjective in nature. Hence, analysis of variance has not been conducted for pilling resistance.

Areal density

An analysis of variance shows that the effect of fiber fineness and noil extraction have a significant impact on the areal density of cotton knitted fabric (Table 4). The P values are lesser than 0.05. Figure 1 is a graphical representation for the effect of fiber fineness, noil extraction, and shade depth on the areal density of cotton melange knitted fabrics.

It is observed from Figure 1, that the areal density of cotton melange fabric increases with the high extraction of noil and low value of fiber fineness. It may be due to an increase of stitch density for high noil extracted and low noil knitted fabrics (Table 4).

Thickness

An analysis of variance shows that the effect of fiber fineness and noil extraction have a significant impact on the thickness of cotton-knitted fabric (Table 4). It is also observed from Table 5 that shade depth does not have a significant impact on the thickness. Figure 2 shows the effect of fiber fineness and noil extraction on different shade depth cotton melange fabrics.

It is observed from Figure 2 that the lower fiber fineness value shows the lesser thickness of the fabric. As the finer fibers have a low bending rigidity which can be pressed to a greater extent during the measurement of thickness due to the dead weight in comparison to the coarse fibers. In addition that yarn with finer fibers possesses a lower diameter (Amjad and Kumar 2020). The lower diameter of yarn also results in the lower thickness of the knitted fabric. It is also observed from Figure 2 that low noil extraction leads to high thickness.

Porosity

Porosity is defined as the void fraction of the total void space contained within the volume of the fabric boundaries and serves the information about the pore volume of the fabric. Analysis of variance shows that fiber fineness and noil extraction have a significant influence on the porosity of cotton knitted fabric (Table 5) while shade depth does not have a significant impact on the porosity as the porosity depends on fabric bulk density and fiber density. In the above case shade depth also does not have a significant impact on bulk density. Therefore, porosity does not affect the shade depth. The effect of fiber fineness and noil extraction on different shade depth cotton melange fabrics is illustrated in Figure 3.

It is observed from Figure 3 that fabrics made from finer fibers give lower porosity. High areal density and lower thickness may be the reason for lower porosity. In addition, the yarn made from finer fibers shows lesser diameter and better integration (Amjad and Kumar 2020). Therefore shows lesser porosity in the fabric. It is also observed that higher noil extraction leads to lower porosity of the fabric which is attributed to the lower yarn diameter and fabric thickness.

Table 3. Properties of cotton melange fabric.

Run	Sample ID	Courses /cm	Wales /cm	Stitch Density (Loops/ cm^2)	Areal density (g/m^2)	Thickness (mm)	Density of Fabric (g/cm^3)	Porosity (%)	Bursting strength (kPa)	Abrasion resistance (cycles)
14	**S1**	15.2	12.72	193.29	138.12	0.58	0.24	84.55	329.4	58000
3	**S2**	15.5	12.99	201.38	142.24	0.52	0.27	82.27	364.4	62500
13	**S3**	15.2	13.78	209.45	143.15	0.51	0.28	81.79	348.6	60000
7	**S4**	16.0	14.00	244.00	148.31	0.48	0.31	79.98	388.2	66500
6	**S5**	13.8	12.20	168.43	125.10	0.65	0.19	87.51	345	60500
12	**S6**	13.7	12.60	172.60	128.00	0.62	0.21	86.59	328.9	57500
4	**S7**	14.5	12.60	182.68	132.00	0.57	0.23	84.96	360.49	65000
5	**S8**	14.5	12.60	182.68	132.00	0.57	0.23	84.96	359.00	65000
10	**S9**	14.5	12.60	182.68	132.00	0.57	0.23	84.96	359.00	65000
8	**S10**	15	13.19	197.83	136.98	0.52	0.26	82.89	412.85	68500
2	**S11**	15.2	13.82	210.05	139.02	0.51	0.27	82.30	390.4	67500
15	**S12**	12.9	11.70	150.93	117.00	0.67	0.17	88.66	361	60000
1	**S13**	13.4	11.81	158.27	122.96	0.61	0.20	86.91	390.5	67500
11	**S14**	13.6	12.20	165.98	124.00	0.60	0.21	86.58	371.2	65000
9	**S15**	14.8	12.99	192.28	129.00	0.54	0.24	84.49	404.23	69500

Table 4. ANOVA results of cotton fabric for physical and mechanical properties.

Factors	Areal density	Thickness	Density of Fabric	Porosity	Max. flow Pore	Mean flow Pore	Bursting strength	Abrasion resistance
FF	S (0.000)	S (0.003)	S (0.000)	S (0.000)	S (0.000)	S (0.000)	S (0.001)	S (0.003)
NE	S (0.000)	S (0.000)	S (0.000)	S (0.000)	S (0.000)	S (0.000)	S (0.000)	S (0.0000)
SD	S (0.020)	NS (0.170)	NS (0.093)	NS (0.093)	S (0.034)	S (0.002)	S (0.004)	S (0.021)
FF×NE	NS (0.136)	NS (0.058)	NS (0.592)	NS (0.592)	NS (0.054)	S (0.016)	NS (0.135)	NS (0.516)
FF×SD	NS (1.00)	NS (1.00)	NS (0.824)	NS (0.824)	NS (0.665)	S (0.021)	NS (0.405)	NS (1.00)
NE×SD	NS (0.390)	NS (0.353)	NS (0.611)	NS (0.611)	NS (0.560)	S (0.045)	NS (0.505)	S (0.272)

F F–Fiber Fineness, N E-Noil Extraction S D- Shade Depth, S- Significant, NS- Non-Significant, Figures within the parenthesis are p- values

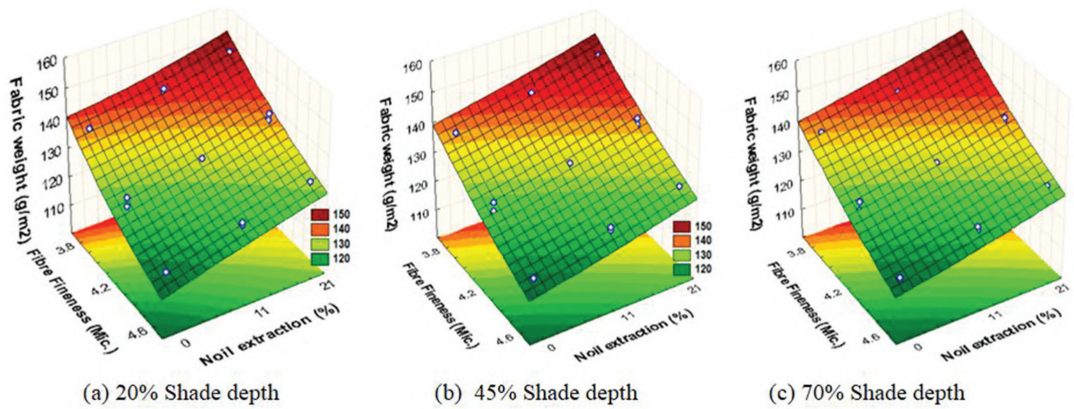


Figure 1. Effect of fiber fineness and noil extraction on the areal density of cotton fabric.

Bursting strength

The strength of the fabric is an essential consideration for the performance of the fabric. Bursting strength is an alternative method for evaluating the strength of knitted fabric in which the fabric is stressed in all directions at the same time. Analysis of variance suggests that the effect of fiber fineness, noil extraction, and shade depth is significant on the bursting strength of cotton knitted fabric (Table 5). Figure 4 is the graphical representation of the bursting strength of cotton melange fabric at different shade depths.

The bursting strength of the fabric mainly depends on the strength and elongation of the parent yarn. Figure 4 depicts that the bursting strength of cotton melange knitted fabric increases with the increase in the value of fiber fineness. Melange yarn made from the finer fibers shows low tenacity and elongation. A fabric consisting of low strength yarns results in low bursting strength.

It is observed from Figure 4 that noil extraction shows a positive effect on the bursting strength. Noil extraction leads to lesser short fibers and proper orientation of the fibers in the yarn. The absence of lower shorter fiber leads to better yarn strength and elongation. Such yarns resist the stress during the bursting strength test and fabric shows better bursting strength.

Table 5. Cumulative and relative weight loss due to abrasion of cotton fabrics.

			Relative weight loss (%)				
Run	Sample ID	Cumulative weight loss (%)	1000 rubs	5000 rubs	25000 rubs	50000 rubs	75000 rubs
14	**S1**	31.03	3.49	5.03	6.84	7.79	12.37
3	**S2**	25.05	0.48	4.52	4.23	6.70	11.72
13	**S3**	29.02	1.97	4.62	5.00	9.49	11.71
7	**S4**	26.78	3.57	5.37	4.30	4.34	11.18
6	**S5**	28.74	0.86	8.12	2.95	6.37	13.91
12	**S6**	31.82	6.76	4.38	4.88	8.46	12.16
4	**S7**	23.70	0.76	3.97	7.22	6.78	7.44
5	**S8**	23.45	1.74	2.13	6.28	7.77	7.91
10	**S9**	23.41	2.29	4.64	8.96	3.61	6.33
8	**S10**	21.21	2.18	1.35	6.42	6.32	7.11
2	**S11**	21.64	1.93	3.86	5.94	5.19	6.80
15	**S12**	29.48	1.35	4.13	5.10	9.78	12.91
1	**S13**	21.15	0.80	3.63	5.61	6.37	6.68
11	**S14**	22.90	1.69	3.92	4.38	4.88	10.25
9	S15	20.34	0.87	4.67	3.20	3.58	9.67

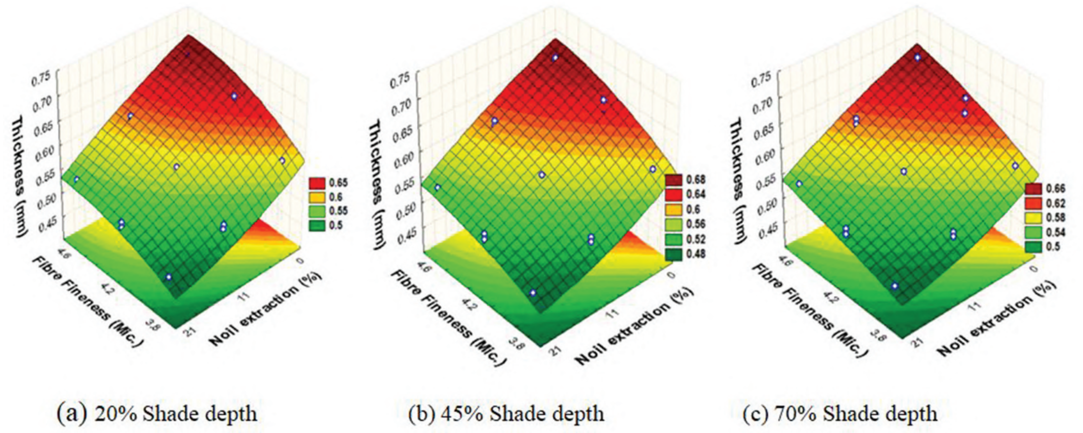


Figure 2. Effect of fiber fineness and noil extraction on the thickness of cotton fabric.

It is also observed from Figure 4 that shade depth negatively impact the bursting strength of the fabric. The fabric made from high depth melange yarns results in low values of bursting strength. High depth yarns are weaker as compared to low depth yarn (Amjad and Kumar 2020). Thus, the multidirectional load-bearing capacity of fabric is lesser and results in low bursting strength.

Abrasion resistance

Fabric can be unsuitable because of several different reasons and one of the most important causes is abrasion. Abrasion occurs due to rubbing during daily practices such as wearing, cleaning, or washing. These processes may result in physical distortion of the fabric, cause fibers or yarns to be pulled out or remove fiber ends from the surface. It not only affects strength but also the appearance of the fabric. An analysis of variance shows that the effect of fiber fineness, noil extraction, and shade depth have a significant impact on the abrasion resistance of cotton knitted fabric (Table 4). The abrasion resistance is evaluated by the maximum revolution required to distort the first yarn of the tested fabric (Table 3). A higher number of revaluation means a higher abrasion

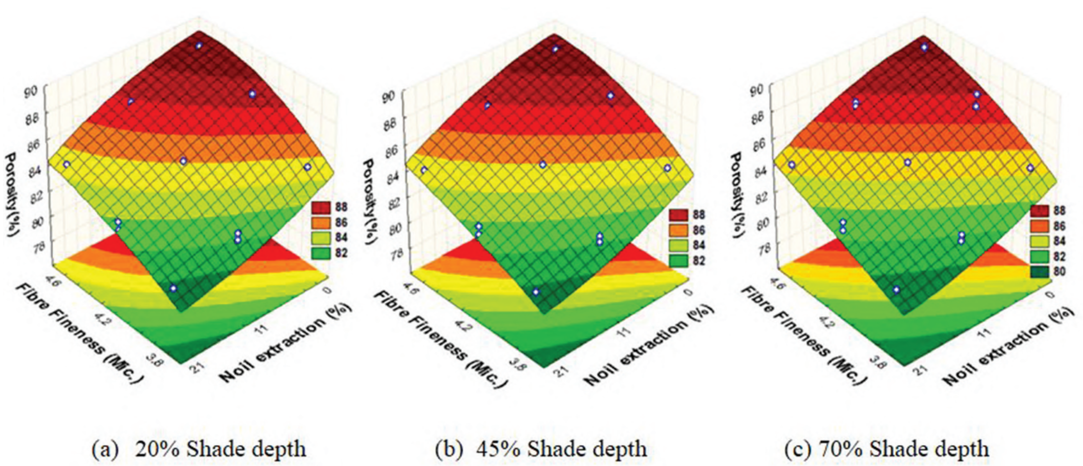
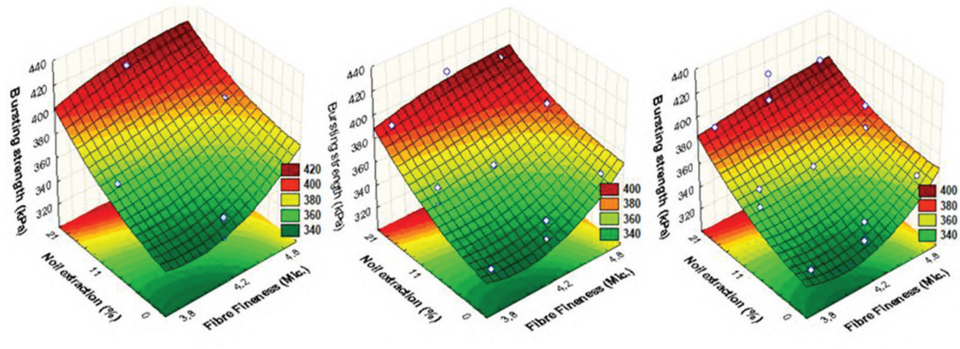


Figure 3. Effect of fiber fineness and noil extraction on porosity of cotton fabric.



(a) 20% Shade depth (b) 45% Shade depth (c) 70% Shade depth

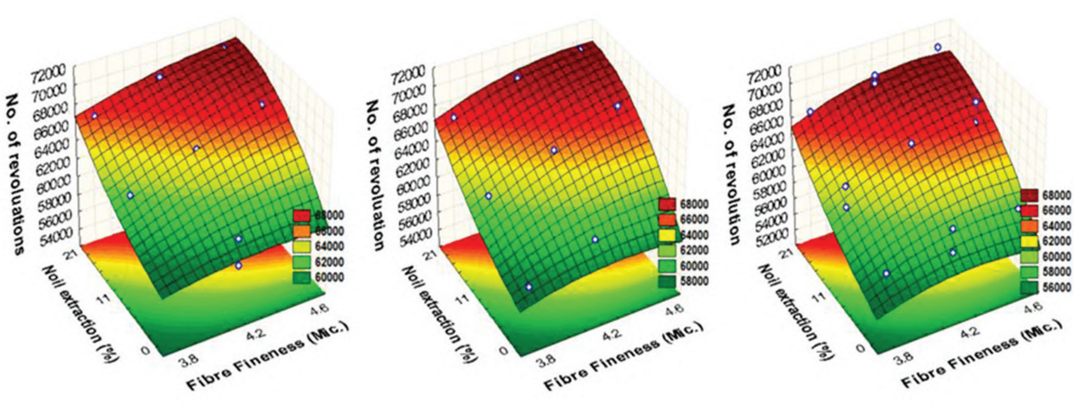
Figure 4. Effect of fiber fineness and noil extraction on bursting strength of the cotton fabric.

resistance, whereas a lower number of revaluation means a lower abrasion resistance. Figure 5 illustrates abrasion resistance. It presents the effect of fiber fineness and noil extraction on different shade depth cotton melange fabrics.

It is observed from Figure 5 that fabric made from finer fibers causes lower abrasion resistance which is contradicting the results obtained for the yarn. In this case, the strength of the parent yarn is dominating factor, due to dyeing and reprocessing yarn produced with finer fiber shows lower strength. Therefore fabric made from such yarns possesses lower strength and abrasion resistance.

It is also observed from Figure 5 that noil extraction shows a positive impact on the abrasion resistance of fabric. The force required to extract the fibers from the yarn structure is one of the causes of high abrasion resistance. Therefore, factors that affect the binding of yarns influence the abrasion resistance of fabrics as well. The high noil extracted fabric consists of longer fibers in the yarn structure. Longer fibers confer better consolidation and harder removal from the fabric structure.

It is also observed from Figure 5 that fabric made from high depth melange yarn shows low abrasion resistance. Yarn hairiness has a negative impact on the abrasion resistance of fabric. The high depth yarn has high protruding fiber on the yarn surface (Amjad and Kumar 2020). An increase in yarn hairiness, due to the higher number of protruding fibers from the yarn surface results in lowers abrasion resistance of the fabric.



(a) 20% Shade depth (b) 45% Shade depth (c) 70% Shade depth

Figure 5. Effect of fiber fineness and noil extraction on abrasion resistance of cotton fabric.

Relative and cumulative weight loss is also measured to find out the abrasion resistance with the help of the weight-loss method. In this method, the fabric is abraded on a Martindale abrasion resistance tester. Weight loss after 1000, 5000, 25000, 50000, and 75000 is measured and reported in the appendix. Relative weight loss and cumulative weight loss for all sets of samples are calculated and shown in Table 5.

It is observed from Table 5 that the trend of cumulative weight loss of the cotton fabric is similar to the abrasion resistance found in Table 3. For all sets of yarn minimum relative weight loss are found for 0 to 1000 rubs and maximum weight loss is found from 50000 to 75000. Initially, fabric shows resistance to the abrasion and there is no pilling formation but furthermore cycle results in disintegrated the fibers from the yarn body. As all the sets of samples distort the first yarn (hole) in between the cycle of 50000 to 75000, it may be the reason for high relative weight loss in this range. Maximum weight loss is found for the combination of 3.8 micronaire, 0% noil extraction 45% shade depth among the tested samples. The effect of fiber fineness, noil extraction, and shade depth on the weight loss due to abrasion is presented in Figure 6.

It is observed from Figure 6 that fabric made from finer fibers losses a higher weight. It is due to the low strength of yarn and poor abrasion resistance of the fabric. It is also observed that weight loss reduces for fabric made from high noil extracted yarns. As previously discussed that high noil extracted fabric, consists of longer fibers in the yarn structure. Longer fibers confer better consolidation and harder removal from the fabric structure.

It is also perceived that high depth melange fabric shows high loss during the abrasion. It is also discussed that high depth yarn shows poor strength and high hairiness. Hence, a fabric made from such yarn will result in high weight loss.

Pilling resistance

The fuzzing and pilling resistance of the fabric is an important characteristic that affects not only the wearability but also the esthetic appearance of textile fabric. Subjective evaluation is done for pilling resistance of fabric. As per standard, six stages pilling test should perform for 125, 500, 1000, 2000, 5000, and 7000 rubs but in this study 5 stage pilling test is done. The study of 125 rubs is avoided because pill formation was not observed at this stage for all sets of samples. Table 6 presents the test results of pilling resistance for different cycles/rubs.

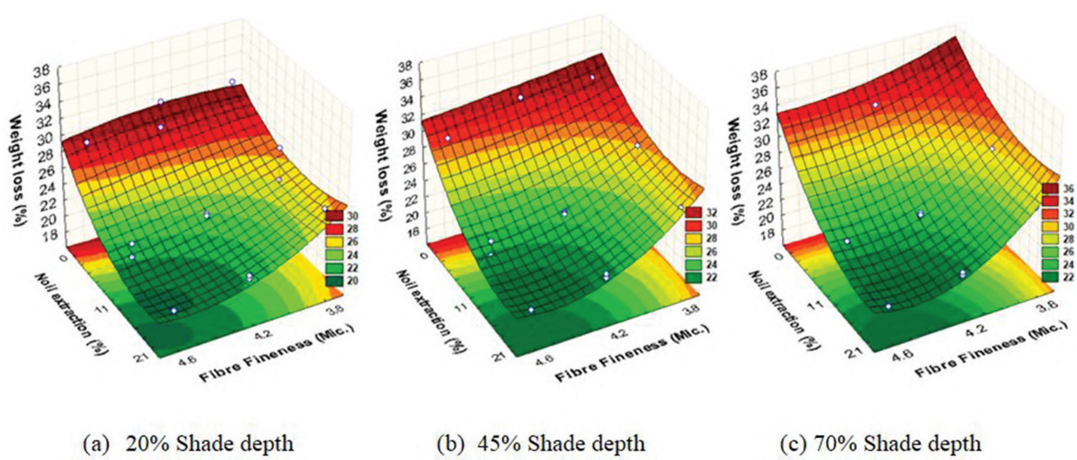


Figure 6. Effect of fiber fineness and noil extraction on weight loss due to abrasion of cotton fabric.

Table 6. Pilling resistance grade of cotton fabrics.

Run	Sample ID	Pilling grade				
		500 rubs	1000 rubs	2000 rubs	5000 rubs	7000 rubs
14	**S1**	5	4–5	4	3	2–5
3	**S2**	5	4–5	4	3–5	3
13	**S3**	5	4–5	4	3–5	2–5
7	**S4**	5	5	4–5	4	3–5
6	**S5**	5	5	4	3	2–5
12	**S6**	5	4–5	3–5	2–5	2
4	**S7**	5	4–5	4	3–5	3
5	**S8**	5	4–5	4	3–5	3
10	**S9**	5	4–5	4	3–5	3
8	**S10**	5	5	4–5	4	3–5
2	**S11**	5	5	4	3–5	3
15	**S12**	5	4	3	2–5	2
1	**S13**	5	4–5	3–5	3	2–5
11	**S14**	5	4–5	3–5	3	2–5
9	**S15**	5	4–5	4	3–5	3

It is observed that fabric made of finer fibers show better pilling resistance. If the fiber fineness is changing, there will be a change in the stiffness. The fiber stiffness is proportional to the square of fineness (linear density) (Varshney, Kothari, and Dhamija 2014). Therefore, finer fiber will not come out from the yarn easily, and there will be fewer fibers on the surface of the yarn. Low noil extraction leads to a high generation of pill due to the presence of a large number of short fibers and high hairiness. Similarly, high depth fabrics also possess poor pilling resistance.

Environment aspect

It is observed that mélange yarn and fabric processing save around 45% water compared to the conventional processing of spinning before dyeing, and reduces around 50% of wastewater. This is due to the utilization of unprocessed/undyed fibers. Consumption of water also depends on the shade depth of the fabric. Higher shade depth leads to higher consumption of water due to the high requirement of water during the melange yarn production. Furthermore, sustainable melange fabrics are value-added fabric and provide a higher margin in comparison to the fabric made using the conventional approaches. Unique esthetic appearance with apparent advantages of water and energy-saving make the sustainable melange fabrics an eye-catching product.

Conclusion

The above study presents an approach toward sustainable fabric manufacturing and an overview of the sustainable organic cotton melange fabric characteristics. The following conclusion can be made from the study:-

Sustainable products are the need of the hour. Sustainable textile products can also be manufactured to taking care of the environment and society. The economic aspect of sustainability can also be fulfilled by the help of value-added textile products like melange textiles. The sustainable approach shows the positive impact on the physical and mechanical characteristics of melange fabrics.

Advancement or manipulation in the raw material and its processing significantly impacts the fabric properties. Fiber fineness and noil extraction have a significant impact on dimensional, mechanical, and physical properties. Shade depth also considerably affects all tested properties of fabrics except thickness, density, and porosity. Higher areal density, lower thickness, and lower porosity of cotton melange fabric with the high extraction of noil and low value of fiber fineness are found.

High extraction of noil and finer fibers leads to lower thickness and porosity while higher areal density. With the increase in noil extraction, the bursting strength and abrasion resistance of cotton melange-knitted fabrics also improve due to a lesser number of short fibers, whereas a reverse trend is observed for shade depth. With the increase in shade depth, the bursting strength and abrasion resistance reduce due to the negative impact on properties of the cotton fiber after dyeing. Higher abrasion resistance of the knitted fabric is achieved by the fabric made from coarse fibers. Fabrics made from the finer fibers and high noil extracted yarn results in a low pilling tendency.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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REGULAR ARTICLE

Effect of Eco-friendly Bamboo Rayon, Lyocell, and Seacell Fibres on the Properties of Blended Knitted Melange Fabrics

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Abstract

New types of fibres like lyocell and seacell have been introduced in the market which is providing unique aesthetic performance and eco values to the melange fabrics. Keeping these considerations in mind, the influence of fibre type, blend ratio, and shade depth on mechanical and physical properties of cotton–bamboo rayon, cotton–lyocell, and cotton–seacell knitted fabrics has been examined. Full factorial design is used to make 18 different samples. Quantitative research was conducted and significant analysis is done by ANOVA. Findings indicate that fibre type and blend ratio significantly impact the dimensional, mechanical, and physical properties, such as stitch density, areal density, thickness, porosity, pore size, bursting strength, and abrasion resistance of cotton blended knitted fabrics. The higher contribution of the cotton leads to the higher areal density and thickness while low pilling and abrasion resistance. Cotton–bamboo rayon melange fabric has the greatest areal density, lowest porosity, lowest bursting strength lowest abrasion, and pilling resistance among the tested samples. Cotton-lyocell blended fabrics show the highest bursting strength and abrasion resistance.

Keywords Melange products · Sustainable textile · Seacell · Mechanical properties · Eco fibres

1 Introduction

The melange effect in yarn or fabric is obtained by mixing two or more distinct colours or filaments in varying ratios, or by cross dyeing the yarn or fabric formed from more than one kind of fibre or filaments [1]. In woven or knitted fabrics, melange yarns provide a distinct colour, an appealing look, and a specialized effect. These yarns can be manufactured in a variety of ways, including ring spinning, open-end spinning, air-jet texturing, air-interlacing, and intermingling [2]. Because of their distinct patterns and value addition to the aesthetic look of the garment, melange yarns and fabrics are a fantastic choice in current apparel trends and fashion [3]. In addition to aesthetic appearance and fashion, sustainability or eco-friendliness of textile material is also getting momentum in recent years. Sustainable raw materials and processes provide value to the fabric while also developing a favourable customer attitude [4]. Biodegradable fibres and GOTS-certified dyes are promising tools for creating eco-friendly garments. Newly regenerated fibres and organic cotton are largely regarded as environmentally benign and are frequently referred to as environment friendly [5]. Regenerated bamboo, also known as bamboo rayon, is a man-made cellulosic fibre that has just entered the market as a textile for clothes and home furnishings and is made from the pulp of bamboo plants by wet spinning [6]. Lyocell, a third-generation fibre, is made by regenerating cellulose in a non-toxic biodegradable organic solvent, N-methyl morpholine-N-oxide hydrate, which is nearly entirely recycled [7]. Seacell, modified third-generation fibres are produced using the lyocell process from sustainable raw materials—wood and seaweed which saves both energy and resources. The fibre is carbon neutral and completely biodegradable. The extraction of seaweed does not harm sea life and grows naturally without using fertilizers and pesticides. Seaweed harvesting is a delicate, selective, and, most important, environment-friendly method. It only removes the part of the algae that can regenerate. Seaweed is entirely untreated and hence retains all of its ecological significance [8]. Seacell fibre contains vitamins, amino acids, carbohydrates, and minerals, resulting in health-promoting fibres with improved skincare

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qualities. SeaCell fibre is easily degradable and breathable, making it ideal for usage in sportswear and underwear [9].

Manufacturing of cloth is a long conversion process from fibre, yarn, fabric to garment. The fibre-to-fabric conversion process is affected by several factors which include properties of basic raw material, process parameters use of technology, machinery, and skill know-how. Properties of fibre, yarn, and fabrics are interrelated to each other [10, 11]. Several researchers [6–8, 12] have investigated these interrelations in terms of plain or normal fabric, but very few studies have been found for melange fabrics. Blending is the most common approach used to find out the impact of different fibres on the yarn and fabric properties. It is also used to enhance the special characteristics of the fabric [13]. According to Arya et al. [14], yarns with varied mix ratios have a substantial impact on yarn diameter, linear density, and dimensional features of knitted fabric, such as loop length, stitch density, tightness factor, loop shape factor, and area shrinkage. The bursting strengths of knitted fabric are greatly impacted by fabric structures, fibre types, and mixes. Mechanical and physical qualities like bursting strength, porosity, abrasion resistance, and pilling resistance can be used to assess the performance of knitted fabric [8, 12]. Several variables influence abrasion and pilling resistance, including fibre type, intrinsic mechanical characteristics of the fibres, fibre dimensions, yarn structure, yarn spinning technology, fabric construction and thickness, and finishing process [6]. Researchers discovered that fibres with high elongation, elastic recovery, and work of rupture can endure repetitive deformation and have a high abrasion resistance [15]. Different fibre shows different abrasion resistance [10]. Fabric made from finer fibres causes an increment in the number of the fibre in cross-section with higher cohesion which results in better abrasion resistance [10, 16].

It has been discovered that several characteristics like blend type, blend ratio, and shade depth have a substantial impact on the mechanical and physical qualities of melange yarns [3, 16, 17]. Thus, such parameters may influence the fabric characteristics. Dimensional, mechanical, and physical properties are also an important criterion to predict the performance of the knitted fabric. In this study, an attempt is made to evaluate the influence of blend type, blend ratio, and shade depth on eco-friendly blended knitted melange fabrics.

2 Experimental Work

2.1 Materials and Design

Cotton and regenerated fibres were used for manufacturing blended melange yarns and fabrics. Dyed and grey H-4 organic combed cotton were blended with bamboo rayon, lyocell, and seacell fibres for producing 19.68 tex (30 s Ne) melange yarns. Seacell fibre which was used in this study was manufactured similar to the process root of lyocell. To maintain the sustainability of the final product, global organic textile standard (GOTS) and Oeko-Tex approved dyes and chemicals were used.

In this study, blending of fibres (dyed/un-dyed, cotton, or regenerated cellulose) was done at the blow room to achieve an ideal regularity of colour and structure. The fineness of the grey cotton, bamboo viscose, lyocell, and seacell fibres is 4.2 micronaire, 1.4 denier, 1.4 denier, and 1.5 denier, respectively. Similarly, the length of grey cotton, regenerated fibres are 29.3 and 38 mm, respectively. Short staple ring spinning is used to produce light (20% fibres are dyed) and dark (70% fibres are dyed) melange yarns by blending three different fibres and blending compositions with cotton. Pre-treatment of fibres was followed by dyeing. GOTS approved reactive dyes were used with sequesterant/dispersant agent 0.5 gpl and ground salt 60 gpl. Dosing with backwash is also done with soda ash 10 gpl, alkali buffer 5 gpl, and caustic flax 1 gpl. The percentage of the dyed fibre in the melange yarn/fabric is known as shade depth. Cotton fibre is preferably dyed to maintain homogeneity in all varieties of melange yarn samples. In the case of a higher contribution of cotton fibre and lesser shade depth, grey cotton fibres are used, while in the case of lesser cotton contribution and higher shade depth, dyed regenerated fibres are used for manufacturing the yarn. Cotton/regenerated fibres are pre-treated with strength and hairiness results are given in Table 1. Single jersey knitted fabrics are manufactured by these yarns with gauge 24 needles/inch, no. of feeder 4, and loop length 2.8 mm. All the process variables are kept constant.

Full factorial design is applied for three factors; fibre type, blend ratio, and shade depth. A total of 18 yarn samples were produced according to design. Table 2 presents

Table 1 Strength and hairiness parameters of cotton blended melange yarns

Shade depth	70%									20%								
Blend	C/B V			C/L			C/S			C/B V			C/L			C/S		
Cotton contribution	30%	50%	70%	30%	50%	70%	30%	50%	70%	30%	50%	70%	30%	50%	70%	30%	50%	70%
Tenacity (gf/tex)	12.8	13.8	14.2	16.0	15.4	15.1	13.3	14.2	14.9	13.8	14.12	14.6	16.8	16.0	15.5	15	15.2	15.6
Hairiness	5.3	5.45	5.8	5.5	5.9	6.3	5.5	5.85	6.4	5.01	5.3	5.6	5.4	5.6	6	5.3	5.55	6.1

Table 2 Experiment design plan for cotton blended yarns and fabrics

Sr. no.	Factors	Levels		
1	Blend type	Cotton/bamboo rayon (C/BV)	Cotton/lyocell (C/L)	Cotton/seacell (C/S)
2	Blend ratio	30/70	50/50	70/30
3	Shade depth (%)	20 (Light)	70 (Dark)	

the ranges and the levels of the experimental parameters in the present investigation. For the statistical analysis and significance, analysis of variance (ANOVA) was carried out with three factors and there levels. A separate t test was run for the nine different conditions of fixed blend ratio, blend type, six different conditions of fixed shade depth, blend type, and six different conditions of fixed shade depth and blend ratio. Post hoc Tukey (honestly significant difference) was also done to determine the grouping of subgroups.

2.2 Test Methods

The physical and mechanical properties of cotton blended melange fabrics were evaluated in accordance with standards. To eliminate impurities, the melange knitted fabrics were pre-treated with 1% anionic surfactant in 1 L of water. The treatment lasts 45 min at boiling temperature. Post-treatment, the samples were completely washed with neutral p^H water and put for 1 day for drying and conditioning at 20º ± 2 ºC and 65% ± 2% RH.

The course per centimetre and wales per centimetre were counted with the help of pick glass, and ten readings were taken. Stitch density is the number of loops per unit area, which was calculated according to ASTM D 3887, by multiplying the number of wales and courses per unit length. The stitch density was calculated as follows: Stitch density in $cm.^2$ = Course per cm x Wales per cm [22]

After relaxing and conditioning the knit fabric samples, the areal density of the samples was determined using ASTM D3776 test method. Fabric thickness tests were performed in accordance with ASTM D 1777–96 for knitted fabric, and ten readings of each sample were taken [23, 24].

The porosity of textile fabric is known as the ratio of open space to the total volume of the fabric, and accordingly, it was calculated from the measured thickness and weight per unit area values using the following equations [18]:

$$\text{Fabric porosity}\ \% = 1 - \frac{\text{Fabric density}\ (g/cm^3)}{\text{Fabric density}\ (g/cm^3)} \times 100,$$

where

$$\text{Fabric density} = \frac{\text{Fabric GSM}}{\text{Fabric thickness in m}}.$$

The bursting strength of each of the knitted fabrics was tested per ASTM D3787-01, and ten readings of each sample were taken. The abrasion property was examined using a Martindale abrasion tester in accordance with EN ISO 12947 part 2 (Determination of specimen breakdown) and part 3 (Determination of mass loss). A 140 mm-diameter fabric sample was fixed at the base platform, and an abrader (woven worsted wool) was attached at the top holder. A controlled quantity of abrasion was applied, and the endpoint was determined by the number of revolutions necessary to deform the first strand or hole in the fabric specimen [25]. The mass loss of the material before and after testing was determined to the closest 1 mg for each of the following rubs: 1000, 5000, 30,000, 60,000, and 90,000.

Fabric specimen pilling was quantified using the ISO 12945-2 standard for 500, 1000, 2000, and 7000 multi-directional rubbing cycles. Due to the lack of evident pill formation/fuzziness in all sets of samples, the study of pilling resistance at 125 rubs is avoided. After each completed rubbing cycle, the specimens were graded with standard photographs. Grade 5 for no change, 4 for slight surface fuzzing and/or partially formed pills, 3 for moderate surface fuzzing and/or moderate pilling, 2 for distinct surface fuzzing and/or pilling, and 1 for dense surface fuzzing and/or severe pilling were assigned [26].

3 Results and Discussion

The effect of fibre type, blend ratio, and shade depth on cotton blended knitted melange fabrics was investigated. The findings of dimensional, mechanical, and physical parameters, such as courses, wales per inch, stitch density, areal density, porosity, bursting strength, abrasion resistance, and pilling resistance, are shown in Table 3. To explore the effect of blend type and blend ratio, on dependent variables, separate ANOVA tests are done, and the results are shown in Table 4a and b. Further. *T* test is also performed to explore differences between subgroups and represented in Table 4c–e. In which effect of a factor on dependent variables are reported in fixed levels of two other factors. ANOVA and t test are not done for the pilling test as the pilling variable has ordinal values.

Table 4 shows that the lowest thickness, porosity, and stitch densities are found in the fabric made from

Table 3 Physical and mechanical properties of cotton melange fabric

Sr. no.	Type of blend	Blend ratio	Shade depth (%)	Courses (cm)	Wales (cm)	Stitch density (Loops/cm^2)	Areal density (g/m^2)	Thickness (mm)	Density of fabric (g/cm^3)	Porosity (%)	Bursting strength (kPa)	Abrasion resistance (cycles)
1	C/B V	30/70	70	16.9	15.75	266.14	157.94	0.51	0.31	79.63	315.74	53,000
2	C/B V	50/50	70	16.5	15.35	253.35	147	0.54	0.27	82.09	367.36	56,500
3	C/B V	70/30	70	16.2	14.96	242.36	144	0.57	0.25	83.38	395.37	60,000
4	C/L	30/70	70	17.1	16.93	289.49	151.96	0.55	0.28	81.82	482.47	75,500
5	C/L	50/50	70	15.8	16.54	261.26	144	0.58	0.25	83.67	448.76	70,000
6	C/L	70/30	70	15.7	16.14	253.43	140.21	0.61	0.23	84.88	421.58	67,000
7	C/S	30/70	70	16.5	16.70	275.55	153.92	0.53	0.29	80.89	435.23	70,500
8	C/S	50/50	70	17	16.00	272.00	146.78	0.57	0.26	83.06	426.30	68,500
9	C/S	70/30	70	17.2	15.35	264.09	142	0.59	0.24	84.17	415.70	65,500
10	C/B V	30/70	20	16.4	16.30	267.32	158	0.51	0.31	79.62	348.65	57,000
11	C/B V	50/50	20	16.9	15.67	264.81	150.31	0.54	0.28	81.69	401.59	59,000
12	C/B V	70/30	20	17.1	15.28	261.21	142.45	0.57	0.25	83.56	420.06	62,500
13	C/L	30/70	20	17.8	17.34	308.65	151.21	0.56	0.27	82.24	509.40	80,500
14	C/L	50/50	20	16.9	16.85	284.77	145.12	0.58	0.25	83.54	454.31	74,500
15	C/L	70/30	20	15.6	16.55	258.18	139	0.6	0.23	84.76	435.66	71,000
16	C/S	30/70	20	17.5	16.45	287.88	154	0.53	0.29	80.88	445.82	76,000
17	C/S	50/50	20	17.3	16.06	277.89	147	0.57	0.26	83.03	438.45	72,500
18	C/S	70/30	20	17.8	15.67	278.91	143.2	0.59	0.24	84.03	428.09	69,000

Table 4 (a) Effect of blend type with fixed blend ratio and shade depth (Anova). (b) Effect of blend ratio with fixed blend type and shade depth (Anova). (c) Effect of blend ratio with fixed blend type and shade depth (t test). (d) Effect of blend type with fixed blend ratio and shade depth (t test). (e) Effect of shade depth with fixed blend ratio and blend type (t test)

Properties						Areal density		Thickness		Porosity		Bursting strength			Abrasion resistance
Factors						Shade Depth (%)									
(a)															
Blend ratio	Blend type					20	70	20	70	20	70	20	70	20	70
30/70	C/B V	C/L			C/S	S	S	S	S	S	S	S	S	`S	S
50/50	C/B V	C/L			C/L	NS	NS	S	S	S	S	S	S	S	S
70/30	C/B V	C/L			C/L	NS	NS	NS	NS	NS	NS	S	S	S	S
(b)															
Blend type	Blend ratio					20	70	20	70	20	70	20	70	20	70
C/B V	30/70		50/50	70/30		NS	NS	NS	NS	NS	NS	S	S	S	S
C/L	30/70		50/50	70/30		NS	NS	NS	NS	NS	NS	S	S	S	S
C/S	30/70		50/50	70/30		NS	NS	NS	NS	NS	NS	S	S	S	S
(c)															
Blend type	Blend ratio					20	70	20	70	20	70	20	70	20	70
C/B V	30/70	50/50				NS	NS	NS	NS	NS	NS	S	S	S	S
	30/70	70/30				S	S	S	S	S	S	S	S	S	S
	50/50	70/30				NS	NS	NS	NS	NS	NS	S	S	S	S
C/L	30/70	50/50				NS	NS	NS	NS	NS	NS	S	S	S	S
	30/70	70/30				S	S	S	S	S	S	S	S	S	S
	50/50	70/30				NS	NS	NS	NS	NS	NS	S	S	S	S
C/S	30/70	50/50				NS	NS	NS	NS	NS	NS	S	S	S	S
	30/70	70/30				S	S	S	S	S	S	S	S	S	S
	50/50	70/30				NS	NS	NS	NS	NS	NS	S	S	S	S
(d)															
Blend ratio	Blend type					20	70	20	70	20	70	20	70	20	70
30/70	C/B V	C/L				**S**	**S**	**S**	**S**	**S**	**S**	S	S	S	S
	C/B V	C/S				**S**	**S**	**S**	**S**	**S**	**S**	S	S	S	S
	C/L	C/S				S	S	S	S	S	S	S	S	S	S
50/50	C/B V	C/L				NS	NS	**S**	**S**	**S**	**S**	S	S	S	S
	C/B V	C/S				NS	NS	**S**	**S**	**S**	**S**	S	S	S	S
	C/L	C/S				NS	NS	S	S	S	S	S	S	S	S

Table 4 (continued)

Properties			Areal density		Thickness		Porosity		Bursting strength			Abrasion resistance
Factors			Shade Depth (%)									
70/30	C/B V	C/L	NS	NS	NS	NS	NS	NS	S	S	S	S
	C/B V	C/S	NS	NS	NS	NS	NS	NS	S	S	S	S
	C/L	C/S	NS	NS	NS	NS	NS	NS	S	S	S	S
(e)												
Blend type	Blend ratio		20	70	20	70	20	70	20	70	20	70
C/B V	30/70		S		NS		NS		S		S	
	50/50		NS		NS		NS		S		S	
	70/30		NS		NS		NS		S		S	
C/L	30/70		S		NS		NS		S		S	
	50/50		NS		NS		NS		S		S	
	70/30		NS		NS		NS		S		S	
C/S	30/70		S		NS		NS		S		S	
	50/50		NS		NS		NS		S		S	
	70/30		NS		NS		NS		S		S	

S significant, *NS* non-significant

cotton–bamboo rayon blended yarns. On the contrary, the highest areal density is found for cotton–bamboo rayon fabric.

3.1 Areal Density

The weight of a one square meter fabric is also known as its areal density (GSM). It is usually determined by constructional characteristics. Figure 1 depicts the graphical influence of fibre type, blend ratio, and shade depth on the areal density of cotton blended melange knitted textiles.

According to Fig. 1, the cotton–bamboo rayon melange fabric has the highest areal density, followed by cotton–seacell and cotton lyocell. As the percentage of cotton in the fabric composition increases, so does the areal density. It may be due to the different stitch densities of the fabrics (Table 3). Loops per unit area depend on the diameter of the yarn and cotton-rich yarn shows the higher diameter due to the shorter length of cotton fibres. Table 4a, b, c, d and e shows that there is a significant impact of the blend type and blend ratio, and significant test shows that the shade depth does not significantly impact on the areal density of the blended fabrics at the blend ratio of 70/30 (P value 0.084) and 50/50 (P value 0.121). It is also observed that blend type does not significantly impact on blend ratio 50/50 and 70/30 among the tested combinations.

3.2 Thickness

One of the most essential dimensional properties of knitted fabric is thickness. Figure 2 depicts the influence of fibre type and blend ratio on various shade depth cotton blended melange fabrics. Figure 2 shows that a larger cotton content in the fabric results in a thicker knitted fabric. Cotton fibres and yarns have greater flexural rigidity than regenerated fibres, and hence, cotton-rich textiles will be less compacted and thicker than regenerated fibre rich fabrics. The length of cotton fibre (29.3 mm) is much lesser than regenerated fibres (38 mm) which may lead to the bulkiness in the yarns made from the high contribution of cotton fibre.

Cotton-lyocell blended fabrics have the maximum thickness followed by cotton seacell and cotton bamboo viscose fabric. There is no significant impact of shade depth found on the thickness. Blend ratio and blend type show a significant impact on the thickness, but in the case of blend ratio (70/30), blend type does not impact significantly (P value for C/BV 0.068, C/L 0.078, and C/S 0.012). It may be attributed to 70% similar content (cotton fibre) in C/BV, C/L and C/S yarns for a 70/30 blend ratio. It is also evident from Table 4a, b, c, d and e that there is no significant difference between the blend ratio 30/70 and 50/50, but there is significant difference between the 30/70 and 70/30.

3.3 Porosity

Porosity influences not only the physical and mechanical properties of knitted fabric but also its comfort attributes. Figure 3 shows the effect of fibre type and blend ratio on different shade depth cotton blended melange fabrics.

Figure 3 shows that increasing the regenerated fibre contribution in the fabric resulted in reduced porosity. The fineness and bending rigidity of the cotton and regenerated fibres used in this investigation are different [13]. The smooth surface of regenerated fibres builds a close association in the yarn and leads to the lowest. Therefore, the change in blend ratio shows different areal density and thickness. With the increase of cotton contribution, areal density increases and thickness decreases at a quicker rate (Table 3). Thus, the ratio of the areal density and thickness increases, and for that reason, the porosity decreases.

Cotton–bamboo rayon blended fabric shows the lowest porosity. As bamboo rayon fibre possesses lower bending rigidity; therefore, the knitted loops in the fabric can be packed together easily and causes the lowest porosity [6, 13]. Thickness and areal density results also validate the reason for the lowest porosity. There is no significant impact of the shade depth on the porosity. Blend type shows a significant impact in the case of blend ratios 30/70 and 50/50, but there is no significant impact on all samples of 70/30 blend ratio. As the porosity is calculated based on the results of thickness and areal density, so similar trend is found.

3.4 Bursting Strength

The bursting strength of a knitted fabric is measured by applying a multi-directional force to it. The bursting strength of the fabric is heavily influenced by basic raw material and fabrication characteristics. According to the statistical investigation, the influence of fibre type, blend ratio, and shade depth on the bursting strength of cotton blended melange knitted fabric is substantial (Table 4). Figure 4 depicts the bursting strength of cotton blended melange fabrics at different shade depths.

The bursting strength of the fabric mainly depends on the strength and elongation of the parent yarn. Figure 4 depicts that the bursting strength of cotton–lyocell blended melange knitted fabrics is maximum among all varieties of fabrics. Lyocell fibres and yarn show good mechanical properties in comparison to other yarns [10]. Lyocell fibres possess high strength high degree of crystalline and molecular orientation in comparison with other fibres [19, 20]. Hence, it gives the best resistance to the multi-directional force during the bursting strength testing.

In the case of cotton–lyocell and cotton–seacell knitted fabrics, the bursting strength decreases with an increasing

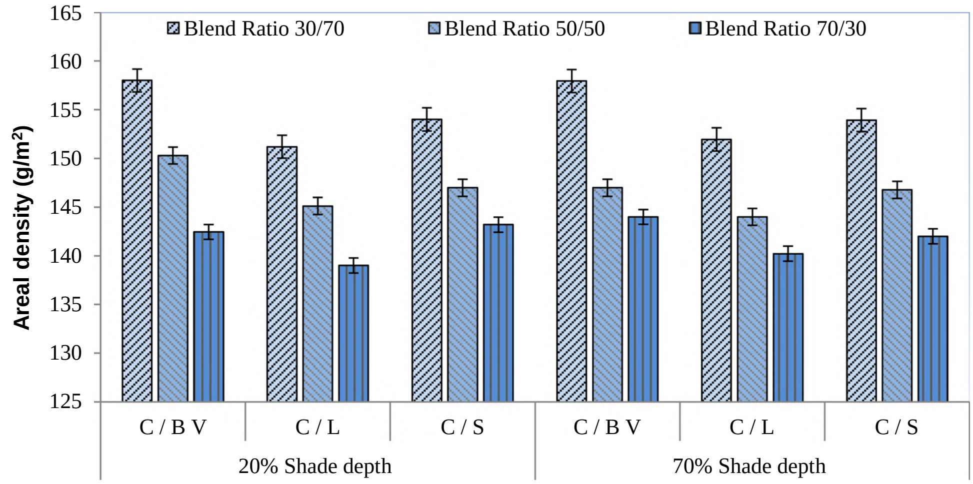

Fig. 1 Effect of fibre type and blend ratio on the areal density of blended fabrics

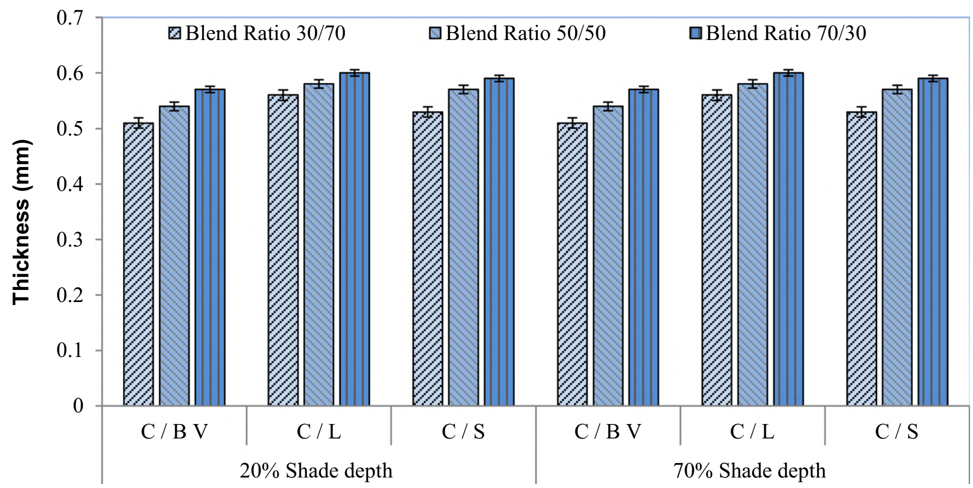

Fig. 2 Effect of fibre type and blend ratio on the thickness of cotton blended fabrics

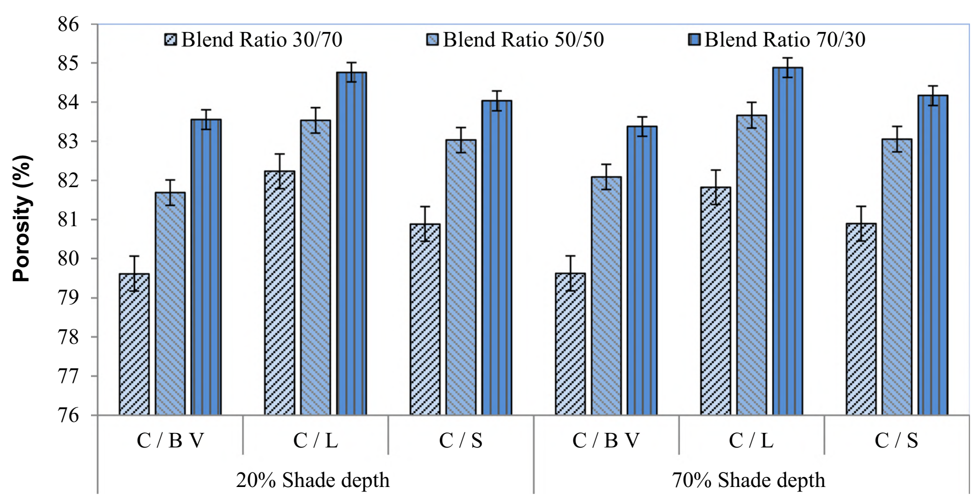

Fig. 3 Effect of fibre type and blend ratio on porosity of cotton blended fabrics

percentage of cotton fibre, whereas bursting strength increases with an increasing proportion of cotton in the case of cotton–bamboo rayon mélange knitted fabrics. In the case of cotton–lyocell fabrics, lesser strength of cotton fibre (29.37 g/tex) in comparison to lyocell (36.23 g/tex) is the reason for the high strength of lyocell rich fabrics, while in the case of cotton–seacell fabric, high strength (29.2 g/tex) and elongation (9.7%) at break of seacell is the deciding factor for high strength of seacell rich fabrics. It is also observed from Fig. 4 that the trend of bursting strength is opposite in the case of cotton–bamboo rayon fabrics. However, bamboo rayon fibre possesses much higher elongation compared to cotton, but the strength is lower (23.2 g/tex). Therefore, bamboo rayon-rich fabric shows low bursting strength.

For all sets of knitted fabric samples, increasing the shade depth results in a decrease in the tendency of bursting strength. When compared to low depth yarns, high depth yarns are weaker [10]. As a result, the fabric manufactured from high depth melange yarns has poor bursting strength values. Table 4a, b, c, d and e also shows that there is a significant impact of blend type, blend ratio, and shade depth on the bursting strength.

3.5 Abrasion Resistance

Abrasion is the physical degradation of fibres, yarns, and fabrics caused by the rubbing of one textile surface against another [15]. According to the analysis of variance, there is a substantial association between knitted fabric abrasion resistance and fibre type, blend ratio, and shade depth (Table 3). Figure 5 depicts the influence of fibre type and blend ratio on various shade depths of cotton blended melange fabrics.

It is observed from Fig. 5 that fabric made from the cotton–bamboo rayon blended yarns gives the lowest abrasion resistance followed by cotton–seacell and cotton–lyocell fabrics. This is due to the lowest tensile strength of bamboo rayon fibre as compared to the other fibres. The lowest strength of the fibre makes the fabrics less durable during rubbing forces. Lyocell fibre shows the highest tenacity (36.23 g/tex) against all other fibres used in the study (Table 1). Therefore, the cotton–lyocell fabric remains durable during the abrasion test.

In the case of cotton–lyocell and cotton–seacell knitted fabrics, the abrasion resistance decreases with an increasing percentage of cotton fibre, whereas abrasion resistance increases with an increasing proportion of cotton in the case of cotton–bamboo rayon melange knitted fabrics. Lyocell and seacell fibres have merits of smoothness and softness against cotton fibre. Cotton fibre length is also lesser in comparison to lyocell and seacell fibre. Therefore cotton-rich blended yarn gives low abrasion resistance in the case of cotton–lyocell and cotton–seacell fabrics. Furthermore, both fibres lyocell and seacell possess much higher elongation against the cotton fibre. The trend for cotton–bamboo rayon fabric is the opposite. In the case of cotton–bamboo rayon fabric, the low strength of bamboo fibre (23.2 g/tex) against the cotton fibre (29.37 g/tex) is deciding factor for abrasion resistance (Table 1).

Abrasion resistance is low in knitted fabric with a high shade depth. Dyeing and reprocessing of the fibre result in significant hairiness and poor yarn strength (Table 1). As a result, high depth fabrics have low abrasion resistance. Figure 6 is a pictorial representation of fabric damage due to abrasion.

Table 5 shows the cumulative and relative mass loss (%) in mg at 1000, 5000, 30,000, 60,000, and 90,000 abrasion cycles for all sets of samples. At the beginning of testing (1000 rubs), the surface was uniform, with no protruding hairs of fibres. Relative loss at 90,000 cycles for cotton–bamboo rayon indicates 0%, which denotes that these samples have already failed at 60,000 rubs. Such samples are not used for measuring the weight loss at 90,000 rubs.

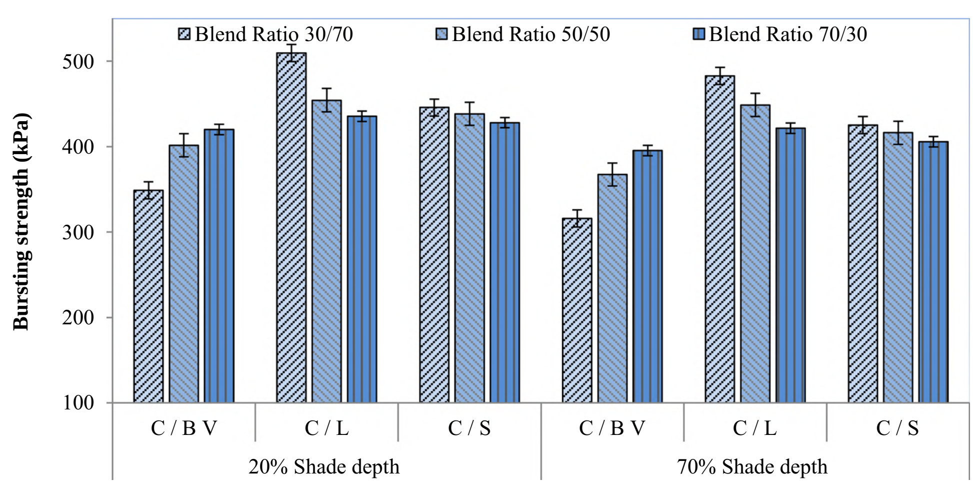

Fig. 4 Effect of fibre type and blend ratio on bursting strength of cotton blended fabrics

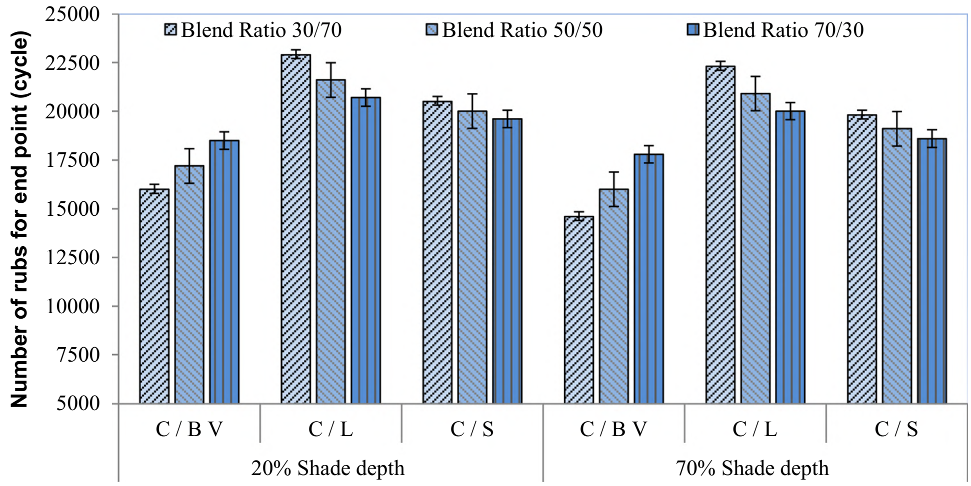

Fig. 5 Effect of fibre type and blend ratio on abrasion resistance of cotton blended fabrics

Table 5 indicates that in the case of cotton–lyocell and cotton–seacell knitted fabrics, the weight loss decreases with an increasing percentage of cotton fibre, whereas weight loss increases with an increasing proportion of cotton in the case of cotton–bamboo rayon mélange knitted fabrics. The trend is similar to the maximum abrasion cycle method (Fig. 5). Reason has also been explained in the previous paragraph. The trend for shade depth is also the same and the reasons already explained in the case of abrasion resistance. Higher shade depth leads to more number of fibre in the fabric and such fibres are more prone to abrasion due to changes in surface characteristics and lower strength. Table 4a, b, c and d also shows that blend type, blend ratio, and shade depth possess significant impact on the bursting strength.

3.6 Pilling Resistance

The fuzziness and pilling of fabric/apparel impact not only the wearability but also the aesthetic value of the fabric/apparel. Fabric pilling behaviour might change due to changes in fibre structure, particularly the surface of the fibre. Table 6 shows the pilling resistance of fabric in terms of grade at various cycles. Due to the lack of evident pill formation/fuzziness in all sets of samples, the study of pilling resistance at 125 rubs is avoided.

From Table6, it is perceived that there is different pilling resistance for blended knitted fabrics made from different fibres. Up to the 500 cycles, there is no deviation in the surface appearance to original fabrics for all sets of samples. At 1000 cycles, slight fuzziness is visible for cotton–bamboo rayon fabric. After 2000 cycles, there is fuzziness/pilling is visible on the surface of all sets of samples except lyocell and seacell rich fabrics. Figure 7 is a graphical representation of the effect of fibre type and blend ratio on the pilling resistance of cotton blended fabrics at two different shade depths.

It is observed from Fig. 7 that a higher proportion of cotton fibre in the fabric leads to poor pilling resistance of the blended fabric. It may be attributed to the reduced mean length of the fibre (29.3 mm) and high hairiness value for cotton-rich yarns (Table 1).

It is also observed that cotton–bamboo rayon blended fabric shows the lowest pilling resistance. It may be attributed to the different surface structures of fibres [19–21]. There is a marginal difference in pilling resistance between the cotton–seacell and cotton–lyocell fabrics. It may be attributed to the almost similar surface structure of the lyocell and seacell fibres. There is no clear visible trend of shade depth on the pilling resistance of blended fabrics.

4 Conclusion

Textile materials are being utilized at a higher pace as a result of fashion's unique look and obsolescence. The fibre, blend composition, and contribution of coloured fibres all have a role in determining the qualities of melange textiles. Organic cotton, bamboo rayon, lyocell, and seacell are examples of eco-friendly fibres that improve not only fabric quality but also environmental qualities. The influence of fabric raw material and shade depth was detected in the investigation. The obtained trend can be viewed in light of the improved fabric performance.

Cotton–bamboo rayon melange fabric has the greatest areal density, followed by cotton–seacell and cotton lyocell. Cotton-lyocell blended fabrics show the highest thickness in comparing cotton–seacell and cotton–bamboo rayon fabrics. Cotton-rich fabrics have a higher areal density and thickness. Increases in the contribution of regenerated fibre to the fabric result in reduced porosity. The cotton–bamboo rayon blended fabric has the lowest porosity value when compared to cotton lyocell and cotton seacell blended textiles. Except for cotton–bamboo textiles, increasing the cotton fibre input

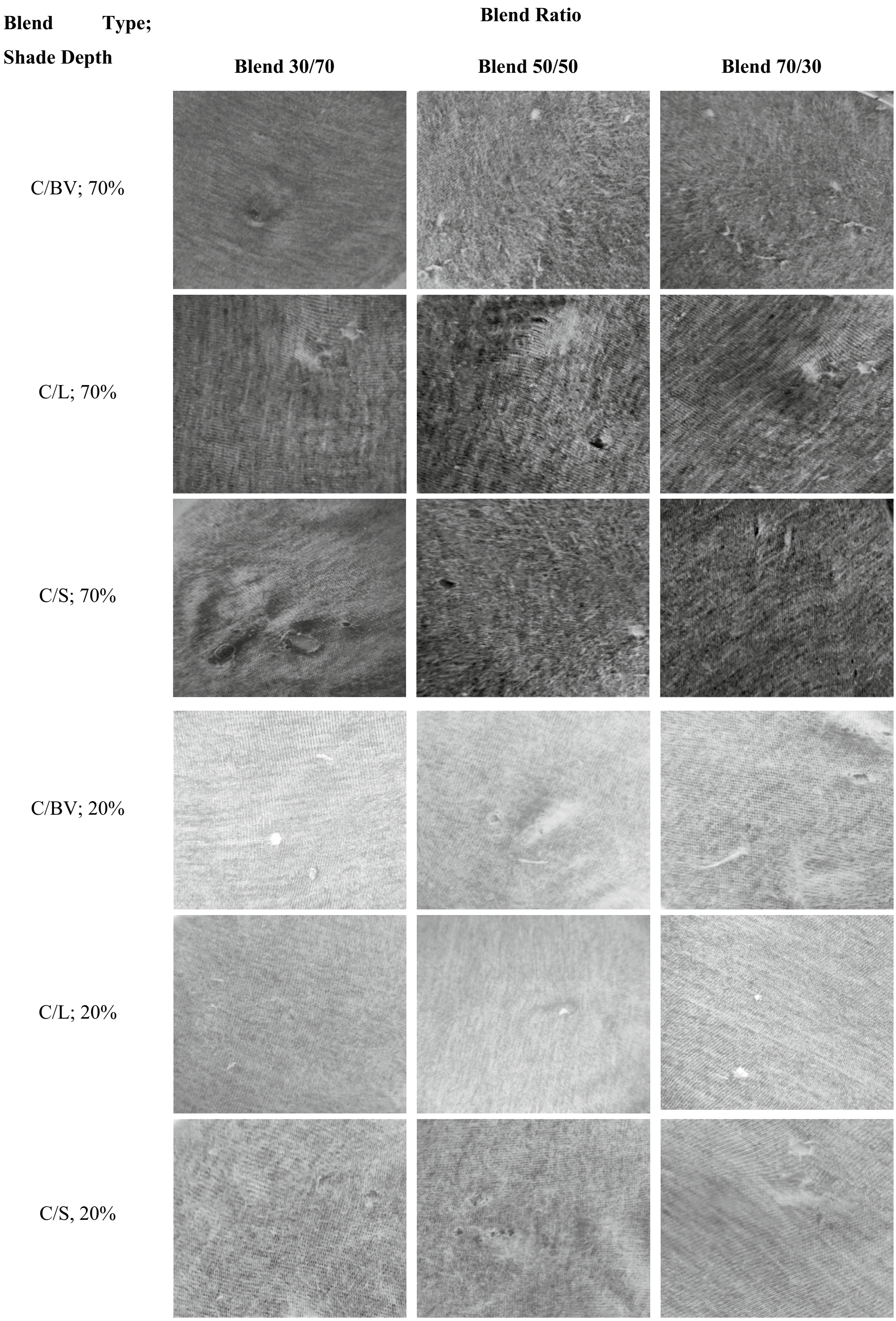

Fig. 6 Surface appearance of fabric at maximum abrasion cycle

Table 5 Cumulative and relative weight loss due to abrasion of blended fabric

Sr. no.	Type of blend	Blend ratio	Shade depth (%)	Initial weight (g)	Final weight (g), after 90,000 cycles	Cumulative weight loss (%)	Relative loss (%)				
							1000 rubs	5000 rubs	30,000 rubs	60,000 rubs	90,000 rubs
1	C/B V	30/70	70	2.434	1.819	25.26	2.19	8.40	1.77	15.07	–
2	C/B V	50/50	70	2.42	1.825	24.61	2.73	7.05	4.43	12.75	–
3	C/B V	70/30	70	2.264	1.762	22.16	2.40	6.05	3.55	11.99	0.00
4	C/L	30/70	70	2.365	1.746	26.17	0.71	6.37	4.30	4.44	13.16
5	C/L	50/50	70	2.423	1.727	28.74	0.86	8.12	2.95	6.37	13.91
6	C/L	70/30	70	2.564	1.773	30.84	1.83	8.32	3.36	5.68	15.69
7	C/S	30/70	70	2.623	1.760	32.89	2.31	7.87	3.29	6.78	17.29
8	C/S	50/50	70	2.432	1.592	34.56	1.74	6.31	5.23	9.43	17.17
9	C/S	70/30	70	2.55	1.633	35.96	1.88	8.27	6.78	8.32	16.74
10	C/B V	30/70	20	2.564	1.982	22.70	2.82	6.58	6.26	9.17	–
11	C/B V	50/50	20	2.413	1.939	19.64	1.71	6.52	6.13	6.82	–
12	C/B V	70/30	20	2.648	2.143	19.07	2.21	7.96	5.17	5.18	–
13	C/L	30/70	20	2.692	2.227	17.26	0.67	3.96	6.25	2.67	4.94
14	C/L	50/50	20	2.632	2.108	19.89	1.14	5.12	3.19	3.58	8.51
15	C/L	70/30	20	2.645	2.051	22.45	1.62	4.67	2.39	4.38	11.40
16	C/S	30/70	20	2.598	1.953	24.83	1.76	6.43	4.45	5.38	9.56
17	C/S	50/50	20	2.5	1.761	29.55	0.80	7.67	5.85	7.59	11.60
18	C/S	70/30	20	2.496	1.795	28.10	1.68	4.38	4.88	8.46	12.16

Table 6 Pilling resistance grade of blended fabric

Sr. no.	Type of blend	Blend ratio	Shade depth (%)	Pilling grade				
				500 rubs	1000 rubs	2000 rubs	5000 rubs	7000 rubs
1	C/B V	30/70	70	5	5	4–5	3–4	3
2	C/B V	50/50	70	5	4–5	4	3	2–3
3	C/B V	70/30	70	5	4–5	4	3	2–3
4	C/L	30/70	70	5	5	5	4–5	4
5	C/L	50/50	70	5	5	4–5	4	3–4
6	C/L	70/30	70	5	5	4–5	3–4	3
7	C/S	30/70	70	5	5	5	4	3–4
8	C/S	50/50	70	5	5	4–5	3–4	3
9	C/S	70/30	70	5	5	4–5	3–4	3
10	C/B V	30/70	20	5	5	4–5	3–4	3–4
11	C/B V	50/50	20	5	4–5	4–5	3–4	3
12	C/B V	70/30	20	5	4–5	4	3	2–3
13	C/L	30/70	20	5	5	5	4–5	4
14	C/L	50/50	20	5	5	5	4	3–4
15	C/L	70/30	20	5	5	4–5	3–4	3
16	C/S	30/70	20	5	5	5	4–5	4
17	C/S	50/50	20	5	5	4–5	4	3
18	C/S	70/30	20	5	5	4–5	4	3

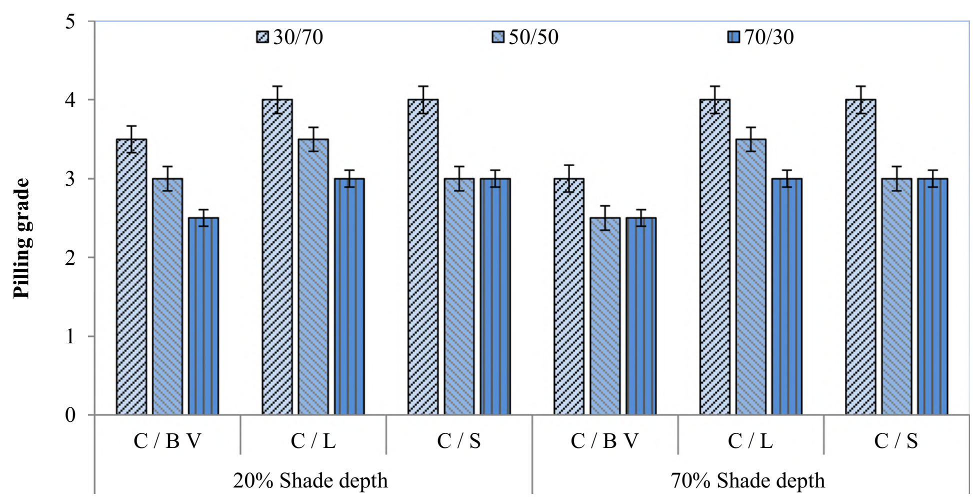

Fig. 7 Effect of fibre type and blend ratio on pilling resistance of cotton blended fabrics at 7000 rubs

reduces fabric breaking strength and abrasion resistance. Cotton–bamboo rayon blended yarns have the lowest bursting strength and abrasion resistance, whereas cotton–seacell and cotton–lyocell textiles have the highest. This is due to bamboo rayon fibre's lower tensile strength compared to other fibres. Cotton-rich fabrics have a low pilling resistance. Cotton–bamboo rayon blended fabric shows the lowest pilling resistance.

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Data availability The authors confirm that the required data supporting the findings of this study are available within the article. Few supplementary data of this study are available from the corresponding author, [Akhtarul Islam Amjad], upon request.

Declarations

Conflict of Interest Authors do not have the potential conflict of interest.

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Abstract:

In recent times sustainability issues are gaining momentum in several manufacturing industries, including apparel and textiles, due to increased market awareness, advancement of industrialization and tougher global legislation. The textile industry causes major environmental impacts due to unsustainable raw materials, production process and life cycle. Sustainable textile has identified the triple bottom line which consists of three basic pillars of Profit (economic), People (social), and Planet (environment). The requirement of sustainability for textile products can be fulfilled by various approaches such as the use of organic raw material, biodegradable material, eco-friendly textile processing, the extent of product life span and recycle of the products. Any manipulation or advancement in the raw material and process may significantly impact the characteristics of textile products.

This research work aims to study the physical, mechanical and comfort (moisture transmission) properties of sustainable melange products. To full fill the requirement of economic, environmental and social sustainability, organic or biodegradable fibres, GOTS approved dyes and chemicals are used to manufacturing sustainable melange textile products. Two sets of melange ring yarns and knitted fabrics with organic cotton and organic cotton-regenerated cellulose fibre have been prepared and properties have been evaluated. In the first set, 100% cotton melange yarns/fabrics were manufactured by varying three parameters - fibre fineness (3.8, 4.2 and 4.6), noil extraction % (0, 11, 21) and shade depth (20, 45 and 70) at three different levels using Box-Behnken design. In the second section ecofriendly cotton blended yarn/fabrics were manufactured from cotton/bamboo viscose, cotton/lyocell and cotton/seacell by varying blend ratio (30/70, 50/50 and 70/30) and shade depth% (20 and 70) using a full factorial design plan. The effect of various raw materials structural and process variables, such as fibre type, fibre fineness, blend composition, noil extraction and shade depth on physical, mechanical and moisture transmission characteristics of melange yarns and fabrics have been studied.

It is observed that raw material and process parameters have considerable effects on physical, mechanical and moisture transmission properties of 100% cotton and cotton blended melange yarns and fabrics. Fibre fineness shows a significant effect on unevenness, tenacity, abrasion, coefficient of friction and diameter properties except breaking extension and hairiness. In the case of bleneded yarns, cotton-rich blended yarns show lower friction, abrasion resistance, elongation while higher hairiness, total imperfection, unevenness and

diameter. Cotton-bamboo blended yarns show the lowest hairiness & abrasion resistance and maximum diameter in all the combination of yarn samples. Cotton-lyocell blended yarn shows a higher tenacity as compared to the other blended yarns. Cotton-bamboo viscose blended melange yarn shows the highest coefficient of friction, the difference between cotton-seacell and cotton-lyocell blended yarns are not significant.

Liquid moisture flows through the yarn is found to be significantly correlated with fibre fineness, noil extraction, blend type, blend ratio and shade depth. For all sets of the sample, the highest attainment of wicking height is achieved by the yarn made from cotton-lyocell fibres and the lowest attainment is observed for cotton-bamboo fibres. For cotton and blended melange yarns, the wicking height attainment rate is higher initially, after some time rate of wicking reduces and then no further wicking is observed. Higher shade depth cotton melange yarn shows lower attainment of wicking height.

A significant impact of fibre fineness and noil extraction is noted for the dimensional, mechanical and physical properties such as stitch density, areal density, thickness, porosity, pore size, bursting strength and abrasion resistance of cotton melange knitted fabrics. Shade depth also considerably affects the all above properties of fabrics except thickness, density and porosity. Fibre type and blend ratio considerably impact on the dimensional, mechanical and physical properties of cotton blended knitted fabrics. Shade depth also has a significant impact on the all above properties of fabrics except thickness, density and porosity. The areal density of cotton-bamboo viscose melange fabric is highest followed by cotton-seacell and cotton lyocell. Cotton-lyocell blended fabrics show the highest thickness in compare cotton-seacell and cotton-bamboo viscose fabrics. Cotton bamboo viscose blended yarns gives the lowest bursting strength and abrasion resistance followed by cotton-seacell and cotton-lyocell fabrics. This is due to the lowest tensile strength of bamboo viscose fibre against the other fibres. High shade depth knitted fabric shows low bursting strength and abrasion resistance. Cotton rich fabric leads to poor pilling resistance. Cotton-bamboo viscose blended fabric shows the lowest pilling resistance.

The significant impact of fibre fineness, noil extraction and shade depth on the air permeability of cotton melange fabrics have been found. Attainment of wicking height has been found different in the course and wales direction of the fabric which shows that capillary pathways may change the capillary flow rate with the same material in the knitted fabric. The proportion of cotton fibre increases in the yarn, the air permeability and water permeability of the blended knitted fabric decrease irrespective of the blend type. Cotton-seacell knitted fabric has the highest air permeability and water vapour transmission values, followed by the cotton-lyocell and cotton- bamboo viscose samples. This is due to diffusion through the highly porous structure of seacell fibre created by the seaweed particles.

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1. Introduction

The basic needs of human being are food, shelter and clothes. The demand for these three basic needs is gradually increasing. The increase in world demand for clothing is expected to continue not only due to an increase in the world population but also due to standards of living, economic activities and developments. Economic activities and developments invariably mean interfering with nature. Therefore, a special responsibility to protect the environment arises from any kind of industrial activity.

In the present era, clothing is expected much more than just satisfying the basic needs of human beings. Clothing is emerging as a way of expressing wealth, status, occupation, leisure and eco-friendliness. Manufacturing of cloth is a long conversion process from fibre, yarn, fabric to garment. In this process, several unsustainable approaches like the use of harmful chemicals, non-biodegradable raw material, high consumption of water and energy, discharge of hazardous chemicals, effluent and use of non-biodegradable packaging materials create the issue for sustainable textiles and clothing. These issues can be eliminated by the systematic approach to shift the production process towards a clean production process. This can be done with the help of avoid, reduce, reuse and recycle strategies. These days it is not only necessary to manufacture textiles for the people but also to manufacture sustainable textiles to save our environment for the future. Responding to human needs without overcoming nature or culture is called sustainability. Sustainable textile is becoming popular at a very fast rate and has defined three basic pillars: Benefit/Profit (economic), People (social) and Planet (environment). A value-added textile product which is using environment friendly biodegradable raw material (fibre, chemicals, dyes etc) and fulfilling the social requirements may be called sustainable textile products.

Fibre is a basic component of any textile material. Cotton fibre is vastly used textile fibre for clothing but during the cultivation of cotton, the use of large amounts of pesticides, insecticides and water make it less sustainable. Organic cotton and regenerated cellulose fibres may be a promising tool to resolve all environmental problems associated with the textile industries. Regenerated cellulose fibres, such as viscose rayon, bamboo rayon, modal rayon, lyocell and seacell are widely considered good for environmental aspects and often referred to as environment friendly. Similarly, grey yarn made from sustainable raw material may fulfil the need of two aspects such as planet (environment) and people (social) but a low margin of profit. This can make it less suitable for the third aspect (profit). Value-added fancy yarn may be the option for the limitation of the third aspect.

Out of various types of fancy yarn, there are very few sustainable fancy yarns. Sustainable yarns and fabrics from melange yarns can be produced by the use of sustainable fibres, dyes during the manufacture of yarns and fabrics. Melange yarn is a fancy yarn, made from two or more fibre groups with different colours or dye affinities and is known for its attractive colour and appearance. Melange yarn is an example of manipulation of fibre characteristics. Mixing of fibres with different colours could be done either in the blowroom at the start of spinning preparation or by feeding differently dyed fibres to the draw frame. The wavy like effect and a wide range of colour tones due to different coloured fibres blending makes it much popular and rich in look. Melange yarn has a unique dyeing process. It requires different technological know-how as compared to yarn dyeing or fabric dyeing in terms of fibre dyeing, colour matching and mixing of multiple coloured fibres. Melange yarn can present multiple colours in one single yarn, which gives aesthetic comfort in respect to rich colours, slenderness and tenderness. Textile products made of melange yarn has a certain ambiguous cyclical effect. Melange yarns are value-added yarns and are produced to get higher prices due to their aesthetic values with unique colour and fancy effect but the use of unsustainable raw materials, chemicals and high effluent discharge make it less sustainable. Melange yarn produced from organic fibres or biodegradable regenerated fibres along with global organic textile standards (GOTS) approved dyes may fit for all three pillars of sustainability.

Process parameters in spinning affect melange yarn quality and performance. Apart from process parameters, the properties of raw material also influence the quality of yarn. All textile technocrats want to produce a product of desired features to fulfil the requirements of the end-user. Hence, awareness about the fibre properties and effective translation of these properties into yarn properties is essential. Researchers have investigated that wet processing of cotton fibres cause, removal of wax, higher cohesion, greater entanglement and decrease in fibres strength. Mechanical processing of the fibres lead to fibre damage and decreasing of their length parameter. These variations on fibres not only affect the efficiency of the spinning process, but also the mechanical and physical properties of the final yarn and fabric.

Apart from physical and mechanical properties, comfort is an important quality criterion of clothing. Comfort includes aesthetic, physiological and thermo physiological aspects which take care of the well-being of the wearer as well as enhances his performance. Thermo-physiological comfort deals with heat and moisture transmission through the clothing where moisture can be in form of liquid or vapour. Moisture vapour transmission affects the breathability of the fabric. Liquid moisture transmission through the fabric is of critical importance. Superior liquid moisture transmission through the fabric, increases sweat spreading area which improves the dryness sensation and increases the evaporative heat loss by faster drying of sweat. The fabric construction properties in terms of geometry, packing density and structure of the constituent fibres in the yarn, as well as the structure of the fabric, affect the dissipation of moisture.

Some references are available regarding research work on melange yarns and fabrics but very few references are available regarding the use of sustainable fibres and dyes for the production of yarns and fabrics. Hence it was thought to study the effect of raw material and process parameters on the properties of yarns and fabrics made from sustainable fibres and dyes.

Chapter II

2. Literature Review

In term of economic activities, the growth of the global textile market is predicted to reach USD 1350.2 billion by 2027, from USD 920 billion in 2018 (Textile market research, 2020). However, being a rewarding market on one end, the textile industry is like a double-edged sword due to rising concerns about the harmful environmental impacts. These concerns require a high level of monitoring to flourish ecosystems for developing sustainable products. Responding to human needs without overcoming or disturbing nature or culture is called sustainability. In current years, sustainability has become a major requirement in textile manufacturing and development at a very rapid pace (Ghosh and Mohan, 2021). Demands of consumer are increasing for ecologically and socially acceptable products. Sustainable textile has identified the triple bottom line which consists of three basic pillars of Profit (economic), People (social), and Planet (environment) (Yang et al. 2017). Figure 2.1 shows the relation in different pillars of sustainability (Purvis et al. 2018).

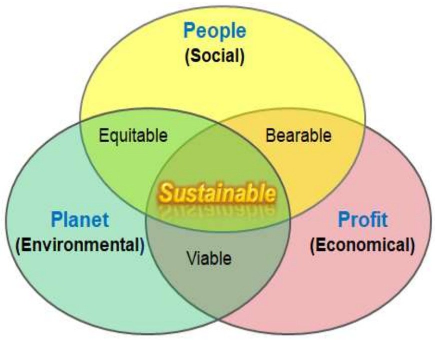

Figure 2.1: Pillars of sustainable product [Purvis et al. 2018].

2.1 Sustainable manufacturing of textile products

The manufacturing of textile products are a long conversion process in the form of fibre, yarn, fabric and garment. The requirement of sustainability for textile products can be fulfilled by various approaches such as the use of organic raw material, biodegradable material, eco-friendly textile processing, and extent of product life span and recycle of the products.

2.1.1 Organic natural raw material

Health-conscious consumers have traditionally preferred natural fibres (primarily cotton) over synthetic clothing; cotton is one of the most preferred sustainable natural crops grown. Consumers now have a growing choice of clothes, bedding and other items made from organic cotton, wool, linen, hemp and flax. The Organic Trade Association recognises that the rising clothing sector is making producers and consumers environmentally aware of organic fibre (Koistra et. al, 2006)

Organic processing does not require the use of chemicals or other artificial processes. Certain environmental issues make them free from dangerous substances and are now being extended to include a wide variety of technological quality and human toxicity requirements and minimum social standards. The Global Organic Textile Standard is recognised as the world's leading manufacturing standard for organic fibre textiles (Brookshire and Norum, 2004). The garment industry is sustainable with basic requirements framed by the Global Organic Textile Standard (Leonas, 2017). It includes organic certification, labelling and licencing that ensure the organic status of textiles from raw materials harvesting through socially responsible manufacturing units to provide reliable consumer assurance.

2.1.2 Biodegradable Raw Material

Apart from natural fibres, regenerated cellulose fibres are biodegradable. Rayon, modal, bamboo, lyocell are known as regenerated cellulose fibres derived from wood pulp, with an average cellulose content of 40%. These fibres are sometimes referred to as 'environmentally friendly.' Modal is a second-generation, known for its softness (Marwaha, 2006). Lyocell is a third-generation fibre technology. Seacell and Smartcell are improved versions of third-generation fibre, the benefits of which include the environmental friendliness of its manufacturing coupled with its softness, drape and antibacterial properties (Ozgen, 2012; Rijavec, 2009). SeaCell™ is manufactured using the lyocell process, a revolutionary and environmentally friendly production method. Production is carried out in a closed loop with no contaminants released as waste. The European Union has been awarded the European Environmental Award for 2000 in the category "Sustainable Development Technology." The patented method securely embeds the algae in a natural cellulose fibre. As a result, the beneficial properties of the algae are permanently preserved within the fibre, even after the algae. As a result, the beneficial properties of the algae are permanently retained within the fibre even after several washing cycles (Venkatesan, 2017; http://www.smartFibre.de/en/Fibres/seacelltm/).

2.1.3 Eco-friendly textile processing

Spinning, weaving and wet process (scouring, washing, dyeing, bleaching, sizing, and finishing) are basic processes to convert fibre to fabric. These processes include environmental concerns such as air, water & soil pollution, wastewater treatment resources, energy use, hazardous materials handling and solid & liquid waste management. Wet processing consumes large quantities of freshwater and discharges large volumes of effluent which generally consist of intense colour, high concentrations of organic compounds, and large variations in composition (Eryuruk, 2012).

Natural dyes or herbal dyes made from plants, marine invertebrates (like sea urchins and starfish), algae, bacteria and fungi may be one alternative for environmentally safe processing. Such colours are not only biodegradable, but they also contain medicinal properties. Eco-bleaching with non-chlorine substances such as hydrogen peroxide can whiten fabrics without producing any harmful chemicals in the process. A common green bleaching procedure uses silicates and natural phosphates which, when used in conjunction with cow dung and exposed to sun bleach, produce natural fabrics. Low-temperature bleaching processes using peroxide activators control its decomposition and at the same time begin to develop the necessary whiteness (Islam et al. 2015; Eryuruk, 2012). GOTS, Reach and Oekotex licenced dyes and chemicals can be another option for the sustainability of textile products. Zero discharge of hazardous chemicals (ZDHC) is also a good initiative for an environmentally sustainable approach to textile manufacturing by post-treatment of wastewater (https://www.oeko-tex.com/en/apply-here/standard-100-by-oeko-tex). Re-use and recycling of wastewater is also a sustainable solution (https://www.roadmaptozero.com/?locale=en).

The use of plasma technology for foam finishing in textiles is a revolutionary approach for the production of stain-repellent, hydrophobic and moisture-management fabrics. Another unique approach that encourages environmental stewardship in textile finishing uses enzymes instead of chemical additives to minimise carbon dioxide emissions and eventually reduce energy usage. Dyeing fabrics with a special enzyme solution eliminates the singing requirement (Scheffer, 2012; Mangat, 2012).

2.1.4 The extent of product life span

Accumulation of soil and dust from bad or careless manufacturing practices and the introduction of insect-infested objects into the collection may affect the life span of the fibres. Infestation causes fibrous cracks due to high humidity condensation. The presence of biological growth, such as moulds or fungi, insects and rodents, attacks organic materials when temperature and humidity are not regulated. Environmental conditions can not alter or stop the spread of mould spores and contribute to the digestion of materials until they begin to expand. This results in a lack of strength and material degradation. The basic nutrition paradigm increases the life span of the fibres. The immortality of fibre can be promoted in the clothing industry (Muthu et al. 2012).

To study the effects of regenerated cellulosic fibres on sustainability, a few studies have been performed. Using the lifecycle assessment (LCA) tool, the environmental effect of these fibres was assessed. In one of these significant studies, LCA was used to analyse regenerated cellulosic fibres provided by Lenzing AG, which accounts for 1/5th of the world's total output of regenerated cellulosic fibres, and to compare the environmental effects of these fibres with those of widely used natural and synthetic fibres (Rana et al. 2014). For evaluation, the sustainability, abiotic degradation, Global warming potential (GWP), depletion of the ozone layer, toxicity for human beings, freshwater ecotoxicity, terrestrial ecotoxicity, formation of photochemical oxidant, eutrophication and acidification have been studied. The effects of polyester and Polypropylene synthetic fibres are greater than those of regenerated cellulosic fibres and cotton (Althuas et al. 2004; Block et al. 2006; Kooistra et al. 2006)

2.1.5 Recyclable eco-friendly fabrics

The recycling process begins with sorting the textiles collected according to their condition and the types of fibre used. Unusable textiles can be sold to the 'flocking' industry for shredding and re-spinning. The first re-sorting shall be performed according to their form and colour. Colour sorting ensures that no re-dying is required to save energy and prevent emissions. It describes high-level environmental requirements across the entire supply chain of organic textiles and also includes compliance with social criteria (Guo et al., 2017). CPET / Polyester waste and post-consumer PET bottles can be recycled for the manufacture of