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Assessment of Ethylene-Vinyl Acetate Material Properties and Compliance Testing for Complete EVA Footwear

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Abstract
Ethylene-vinyl acetate (EVA) is widely used in the footwear industry due to its excellent cushioning, flexibility, and lightweight characteristics. This study investigates the performance properties of EVA material for complete footwear applications, focusing on critical tests including sole abrasion, tear strength, compression resistance, full shoe flexing, and chemical safety parameters such as cadmium, lead, phthalates, and pH value. The analysis combines empirical testing with a review of regulatory compliance standards and existing literature. The results demonstrate (white shoe of density 0.19 g/cc and black shoe of density 0.17g/cc) versatility and potential to meet functional and environmental safety requirements for footwear manufacturing.

1. Introduction

The global footwear industry has increasingly adopted polymeric materials due to their cost-effectiveness and performance benefits. Among them, ethylene-vinyl acetate (EVA) has gained prominence for midsoles, outsoles, and full-shoe constructions. EVA is a copolymer known for its resilience, shock absorption, and formability (Mills, 2011). However, as sustainability and regulatory compliance have become essential to manufacturing, there is a growing need to assess not just the mechanical performance but also the environmental and health safety of EVA-based footwear. EVA is a closed-cell foam with thermoplastic behaviour, formed by the copolymerization of ethylene and vinyl acetate. It is known for its cushioning properties, low-temperature flexibility, and shock absorption, making it suitable for footwear midsoles, customized ortho footwear, and orthotic devices (Redmon et al., 2009). Previous studies emphasize the importance of wear resistance and flexibility in evaluating sole materials. According to Renner and Weidmann (2004), EVA-based soles exhibit strong performance under dynamic flexing and moderate resistance to abrasion, particularly in lightweight applications. With regulatory frameworks such as REACH and CPSIA in place, the presence of heavy metals and phthalates in footwear materials has come under scrutiny. As per Karayiannis and Luciani (2016), EVA used in children's shoes and orthotic devices must meet limits for total cadmium and lead content to ensure user safety. Additionally, proper pH levels must be maintained to prevent skin irritation and material degradation (Broughton, 2017) [1 - 5].

2. Related Work

Table 1 showing the related work along with the research gap and the proposed solution-

Table1 related work along with the research gap and the proposed solution

Study / Author(s)	Material Studied	Test Methods Conducted	Key Findings	Limitations / Gaps Identified	Our Proposed Contribution
Renner & Weidmann (2004)	Standard EVA in running shoes	Abrasion (ISO 4649), Flexing (SATRA), Compression	EVA provides moderate abrasion resistance and good initial cushioning	Did not include chemical safety testing; Limited to midsole use	Include abrasion, full-shoe flexing, and compressive strength for whole EVA-based shoe
Redmond et al. (2009)	Custom EVA orthotic insoles	User satisfaction, Orthotic performance	High satisfaction in orthotic comfort and fit	Lacked mechanical testing and regulatory safety evaluation	Evaluated both mechanical and chemical properties of EVA used in complete footwear
Karayiannis & Luciani (2016)	EVA in children's shoes	ICP-OES for Pb and Cd content	Complies with REACH heavy metal standards	No performance testing of EVA (e.g. cushioning, tear)	Combine mechanical durability + chemical compliance for holistic assessment
Bianchi et al. (2023)	Recycled vs. virgin EVA	SEM analysis, Tensile, Compression, Tear strength	Recycled EVA shows 10–15% lower strength, larger pores	Focused on foam blocks, not whole shoes; No dynamic flexing tests	Test full shoe flexing, abrasion, and tear resistance for real-life durability
Sandu et al. (2024)	CNT/EVA composites	Abrasion, Tear, DSC, DMA	Nanofillers improve abrasion and thermal stability	Limited industrial application; no toxicological tests	Study unmodified EVA used in commercial shoes and perform toxicity/pH/phthalate tests
Lippa et al. (2016)	EVA running-shoe foam & cut-out shoe	Compression fatigue (~160 km equivalent), energy absorption, stiffness	EVA stiffens and loses energy absorption under long-term fatigue	No abrasion, tear, whole shoe test; no chemical tests	Test full shoe flexing, abrasion, and tear resistance for real-life durability along with chemical test
Chang et al. (2023)	EVA foam + 0.5 wt% CNT	Abrasion, compression, dynamic fatigue (250k+ cycles), rebound	CNT reinforcement improves abrasion, stiffness, rebound retention	Nanocomposite focus; foam only; no tear or chemical parameters	Test full shoe flexing, abrasion, and tear resistance for real-life durability along with chemical test
Zhang et al. (2023)	EVA midsole composites	Impact fatigue, energy return (>70%), abrasion, stiffness	MWCNT improves durability, energy return vs traditional fillers	Midsole prototype only; no tear, flex fatigue, or toxicological tests	Test full shoe flexing, abrasion, and tear resistance for real-life durability along with chemical test
Lunchev et al. (2022)	EVA with 0.1–1 wt% graphene	Compression softness, stiffness, abrasion; actual shoe prototypes	Graphene increases stiffness (~30%), softness, abrasion resistance (~40%)	No chemical safety or tear/flex fatigue testing	Test full shoe flexing, abrasion, and tear resistance for real-life durability along with chemical test
Chang et al.	EVA blended	Density,	Blends reduce	Foam-based test	Test full shoe flexing,

(2024)	with POE/TPE	compression, dynamic impact	density and enhance energy absorption/return	only, no tear, abrasion, footwear flex fatigue, or safety tests	abrasion, and tear resistance for real-life durability along with chemical test
Xing et al. (2024)	EVA foam of varied hardness	Dynamic impact / crushing behaviour, energy absorption curves	Captures impact energy and contact force/displacement behaviour	Foam specimen only; mechanical focus; no chemical or whole shoe context	Test full shoe flexing, abrasion, and tear resistance for real-life durability along with chemical test
Shimazaki et al. (2009)	Layered EVA foams	Shock absorption efficiency under simulated heel strike	Functionally graded EVA improves load distribution and cushioning	Foam prototype only; no real shoes, no chemical testing	Test full shoe flexing, abrasion, and tear resistance for real-life durability along with chemical test
Wu J et al. (2023)	Commercial low-density EVA boards	Quasi-static and dynamic compression at varied strain rates	EVA stress–strain response shows strain-rate sensitivity and bounded densification behaviour	Material modelling only; no tear, fatigue, abrasion, or chemical tests	Test full shoe flexing, abrasion, and tear resistance for real-life durability along with chemical test
Proposed Work	Commercial-grade molded EVA shoe	ISO 4649:2017 (Abrasion), SATRA TM 162:2017 (Tear Strength), ST-09 (Compression), SATRA TM92:2016 (Whole Shoe Flexing), EN ISO 17072-2: 2011 (Lead), CPSC-CH-E-1002-08.3: 2012 (Cadmium), CPSC-CH-C1001-09.4:2018. (Phthalates), ISO 3071:2020 (pH)	Comprehensive mechanical and safety profiling of EVA shoe	Existing works fragment testing—none cover all aspects (durability + safety + wear) together	First to combine full-spectrum physical and chemical testing on complete EVA footwear model

3. Materials and Methods

3.1. EVA Material Selection

The granules of EVA are used to prepare white shoe of density 0.19 g/cc and black shoe of density 0.17g/cc. Shoes were prepared using compression melding and cut into samples as per standardized test dimensions. The experimental data of 1000 EVA shoe recorded at ambient temperature 40°C at Leather working School, Dayalbagh Educational Institute, Dayalbagh, Agra using different quantity of EVA material like Black and White and the ideal operating parameters are given in Table 2.

Here are some Assumptions for the following below table 2 [15]

- Assuming the Granule size is also within certain range.
- Assuming the EVA expansion is also constant [6-10].

Figure 1 Side view of Black EVA Shoe

Figure 2 Side view of White EVA Shoe

Table 2 Ideal operating parameters for EVA shoe making [15]

Color	Size	Operating temp.(°C) (Upper plate)	Operating temp.(°C) (Lower plate)	Quantity (gm)(Right foot)	Quantity (gm)(Left foot)	Time (min)
W	6	134	147	102	104	14
W	7	134	147	109	105	14
W	8	134	147	112.5	114	14
W	9	134	147	120.5	120.5	14
W	10	134	147	130.5	128.5	14
B	6	133	140	102.5	104.5	15
B	7	133	140	108.5	105.5	15
B	8	133	140	112.5	113.5	15
B	9	133	140	119.5	119.5	15
B	10	133	140	129.5	127.5	15

3.2. Mechanical Testing Procedures

- Sole Abrasion Test: Conducted according to ISO 4649:2017 using a rotating drum and abrasive paper to simulate long-term wear.
- Tear Strength Test: Followed SATRA TM 162:2017, using angular tear specimens to measure the force required to propagate a tear [11-13].
- Compression Set Test: Conducted as per ST-09 to determine deformation after sustained compressive load at elevated temperatures.
- Full Shoe Flexing Test: Evaluated with SATRA TM 92:2016 (Flexing Angle=35o) to simulate walking cycles; shoes were flexed up to 40,000 cycles.
- High Voltage Testing: The shape of electrodes is flat inside and spherical on outer side of shoe. The experimentation was done on different parts of the EVA shoe as shown in Figure 1 and 2 at electrical HV laboratory, Faculty of Engineering, Dayalbagh Educational Institute. The test was performed according to dielectric shoe testing standard EN 50321:2000 for electrician safety shoe to work on Low Voltage systems [19].

Figure 3 Experimental setup of HV Test Machine

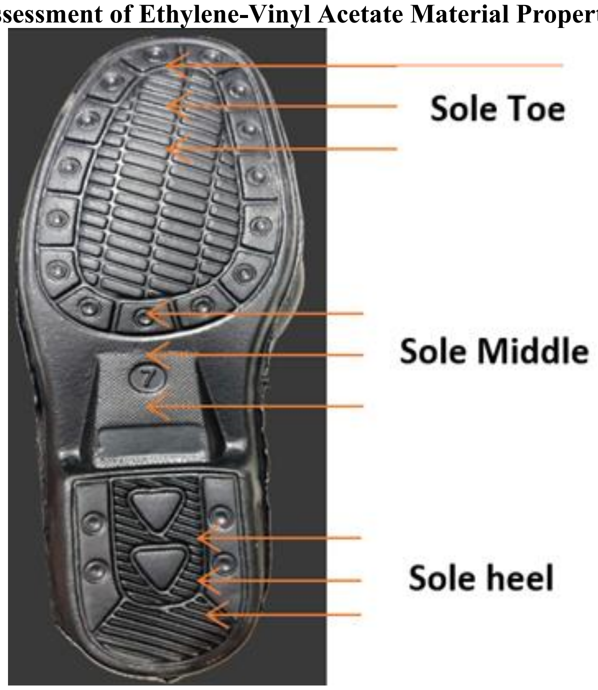


Figure 4 HV Test Performed on EVA Shoe Bottom

3.3. Chemical Safety Tests

- Total Cadmium Content: Assessed via EN ISOO 17072-2:2011
- Total Lead Content: Assessed via CPSC-CH-E-1002-08.3:2012
- Phthalate Content: Assessed via CPSC-CH-C1001-09.4:2018
- pH Value Test: Conducted in accordance with ISO 3071:2020 using aqueous extraction and pH electrode measurement [14].

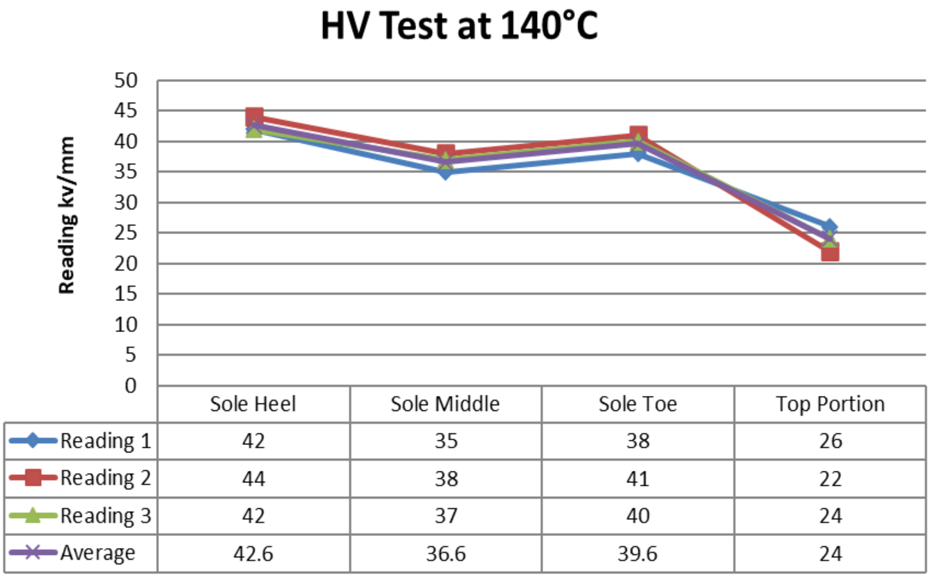
4. Results and Discussion

4.1. Mechanical Performance

The abrasion resistance of EVA white shoe of density 0.19 g/cc is 534 mm^3 (Loss in Volume) and black shoe of density 0.17g/cc is 464 mm^3 (Loss in Volume) which is within acceptable ranges i.e., $\leq$600 mm^3 for athletic and casual footwear. Tear strength averaged 10.85 N of white EVA shoe and 10.75 N of black EVA shoe. Minimum requirement needed 10 N indicating high durability under sudden loads. The compression set was recorded 12.1% of white EVA shoe and 13.6% of black EVA shoe with max. requirement 15% of both EVA shoes signifying strong resilience and shape recovery. Full shoe flexing revealed no visible cracks after 40,000 cycles, demonstrating the material's robustness for daily wear [16].

4.2. Results for Dielectric Strength

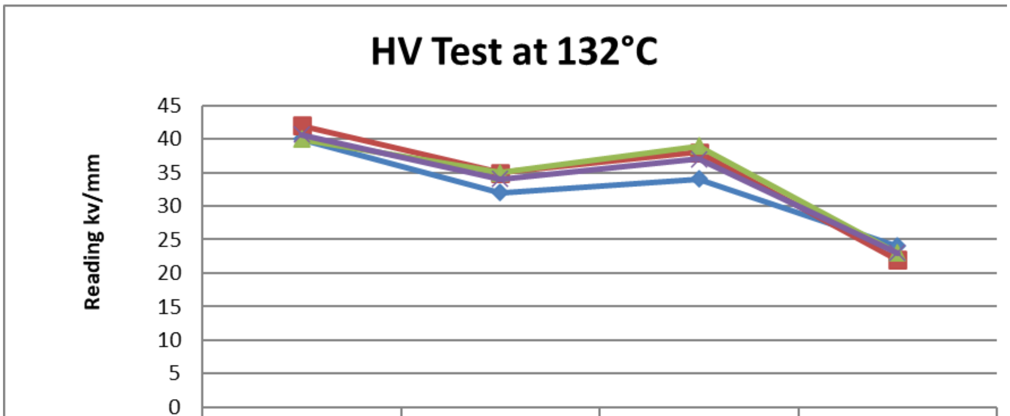
The breakdown strength Eb = Vb / t where, Vb is the breakdown voltage, and t is the sample thickness at the point in which the breakdown occurs [19]. Figure 3 and 4 shows the break down strength of various parts of EVA shoe (Sole heel, Sole middle, Sole Toe, shoe top). The below Table – 3 is showing the results of EVA shoes manufactured at optimal temperature 140°C break down strength under Temperature: 15 °C and Humidity: 87%. Similarly, the Table - 4 is showing the results of EVA shoes manufactured at lower temperature 132 °C break down strength under Temperature: 15 °C and Humidity: 87%



	Sole Heel	Sole Middle	Sole Toe	Top Portion
Reading 1	42	35	38	26
Reading 2	44	38	41	22
Reading 3	42	37	40	24
Average	42.6	36.6	39.6	24

Various Portions of EVA Shoe

Figure 5 Average break down strength of different components of EVA shoe manufactured at 140 °C



	Sole Heel	Sole Middle	Sole Toe	Top Portion
Reading 1	40	32	34	24
Reading 2	42	35	38	22
Reading 3	40	35	39	23
Average	40.67	34	37	23

Various Portions of EVA Shoe

Figure 6 Break down strength of different components of EVA shoe manufactured at 132 °C

Note- The upper portion can bear less voltage, and bottom portion can bear higher voltage Shown in Figure 5 and 6 [17-18].

4.3. Chemical and Environmental Compliance

Total cadmium and lead concentrations in the EVA samples were below detection limit i.e., 10mg/kg and max. requirement was 75mg/kg and 90mg/kg respectively. The phthalate levels were undetectable i.e., 0.005% (Requirement <0.1%), and the pH ranged 4.7 for white EVA shoe and 5.1 for black EVA shoe (Requirement 3.5-7.5 for both shoes), which is skin-friendly and compliant with most global footwear standards (BIS, 2022). These findings indicate that EVA not only meets physical durability requirements but also passes key safety assessments, making it suitable for use in children's and orthopaedic footwear as well.

Conclusion

This comprehensive evaluation of EVA material for complete footwear applications confirms its mechanical integrity and environmental compliance. The material exhibits commendable abrasion resistance, tear strength, compression recovery, and flexibility, while meeting stringent international standards for chemical safety. As the footwear industry continues to pursue sustainable and high-performance solutions, EVA remains a promising material for both mainstream and specialized products. All the results meet the requirement as per the company test report.

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