Usage of Alternate Stator Material instead of Energy-Intensive Materials in 3-Phase Induction Motors used in Industrial Conveyors Using ANSYS Maxwell

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Abstract

The focus on sustainability, reusing materials, and reducing the energy costs of manufacturing modern products is proliferating. Three-phase induction motors use energy-intensive materials in industrial conveyors, such as DW315_50 steel and copper as stator and rotor materials, respectively. Although these materials are efficient and capable, more sustainable and cheaper alternatives in terms of energy cost are available. This study investigates the performance of Somaloy 700HR-5P as the stator material and aluminium as the rotor bar material in a three-phase induction motor with a squirrel-cage type rotor. A finite element analysis is conducted on this motor using ANSYS Electronics to determine the performance characteristics for these low-energy-consuming alternatives. The proposed material offers higher torque, similar efficiency, lower motor weight, high reusability, high sustainability, and cheaper energy costs compared to the currently used materials for industrial conveyors.

1 Introduction

As the global race toward carbon neutrality intensifies, the electric motor industry stands at a pivotal crossroads. With a daunting target from Europe to Asia for net-zero emissions, the pressure to revolutionize material sustainability in motor production has never been greater. Therefore, there is a need to use sustainable materials while also maximising the motor efficiency. Table 1 shows the target year for some countries, by which the country should have achieved net-zero emissions.

Table 1 Target years for net-zero emissions by country [1]

Country	Target Year
Bhutan	Achieved
Suriname	Achieved
Uruguay	2030
Finland	2035
France	2050
China	2060
USA	Undefined
Germany	2045

Carbon emission reduction is no longer a concern for specific industries, but a challenge for all stakeholders capable of driving a meaningful change. The new industrial imperative demands comprehensive Life Cycle Assessment (LCA) approaches: systematic evaluations of a product's carbon footprint across all phases from manufacture through operation to circular recovery.

Induction motors sit at the heart of industrial automation and will undoubtedly remain central to our technological future. Redefining how these motors are engineered is therefore critical, particularly given their staggering market influence: valued at $20.3 billion in 2024 and projected to reach $37.5 billion by 2034, with a 6.4% annual growth rate. Notably, the United States dominates this sector, accounting for 80% of the global market. [2] This paper focuses on three-phase induction motors, which account for 60% of the total market share. [2] Given their massive production scale, even minor improvements in motor efficiency or material recyclability could yield outsized benefits, not just for industry, but for the whole planet.

Steel, the timeless pillar of induction motors, reigns supreme through its reliability and cost-efficiency. Yet aluminium, with its lighter weight, enables new possibilities for a transformed mobility as Tesla's innovations have demonstrated. As for Somaloy, with its complete recyclability, which is a prime candidate for the future of sustainable motor materials. Somaloy demonstrates clear advantages in energy efficiency and sustainability. With lower production energy (25–35 kWh/kg vs. 40–50 for aluminium), reduced CO_2 emissions (4–6 kg/kg vs. 8–12), and superior recycled CO_2 savings (95% vs. 75%).

Having outlined these environmental impacts and advantages of the proposed materials, this paper also evaluates their key electrical performance parameters to compare and analyse if these alternatives also outshine their predecessor in the technical aspects of the machine. A thorough comparison is then established at the end of this paper.

Table 2 Financial information about the materials

Parameter	Unit	Aluminium	Somaloy	DW315
Current price	€/kg	2.5-3.0 [3]	8.0-10.0[4]	5.5-6.5 [5]
Recyclability rate	%	75 [6]	95 [7]	85 [8]
Recycling cost	€/kg	0.8 [9]	1.20 [10]	1.00 [10]
Motor lifespan	years	15 [11]	20 [12]	18 [13]

Table 3 Key parameters of material recycling

Parameter	Unit	Alu	Somaloy	DW315
Production Energy	kWh/kg	40-50	25-35 [14]	30-40 [15]
CO_2 emissions	kg CO_2/kg	8-12 [16]	4-6 [17]	5-7 [18]
Recycling energy	kWh/kg	5-8 [19]	3-5 [20]	4-6 [21]
Recycled CO_2 savings	%	75 [22]	95 [7]	85 [23]

2 Theory

Electric motors convert electrical energy into mechanical energy. Induction motors are commonly used because of its robustness, inexpensiveness and simplicity of use and control. The alternating current induction motors normally run at a fixed speed and changes slightly when a mechanical load is applied to the rotor shaft. [24]

A typical three-phase induction motor consists of the frame, the lamination core, the three-phase winding, the rotor shaft, the laminated magnetic core, rotor bars, and short-circuit rings. Other auxiliary components include end shields, fan, fan cover, terminals and bearings. Figure 1 shows a cut-away model of the motor. [24] [25]

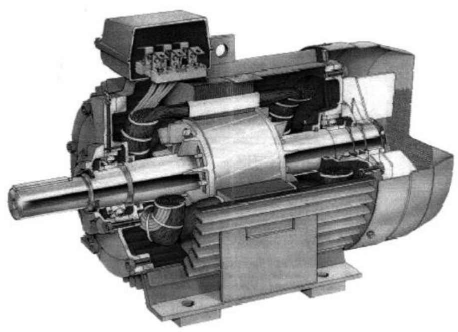

Fig. 1 Low-power three-phase IM with cage rotor

The basic principle behind the function of an induction motor is electromagnetic induction. When electric current flows through a three-phase winding displaced 120° to each other, the various currents will generate their own magnetic fields. These create a rotating magnetic field which the rotor follows at a speed less than the synchronous speed. The synchronous speed can be calculated using the below equation. [24] [26]

$$n_s = \frac{120.f}{p}\ rpm \ (1)$$

The synchronous speed n_s can be calculated using f as the supply frequency and p as the number of poles. When there is difference between the actual motor speed and the synchronous speed, then it is an asynchronous motor and this parameter is called slip. It is calculated using the below equation. [24]

$$s = \frac{n_s - n}{n_s}.100\ \%\ (2)$$

The efficiency of the motor is calculated with the input power and output powers using the following equation. [24]

$$\eta = \frac{P_{in}}{P_{out}}.100\ \%\ (3)$$

The three-phase induction motor with DW315_50 steel and copper used here has the parameters as described in Table 4.

Table 4 Electrical specification for both the motor to be compared [27]

Parameter	Value	Units
Rated power	5.5	kW
Number of poles	4	count
Synchronous speed	1500	rpm
Operating temperature	75	°C
Slot fill factor	80	%
Rated voltage	380	V
Winding connection	Delta	Type
Rated frequency	50	Hz

The physical and mechanical properties of DW315_50 and Somaloy 700HR-5P are illustrated in Table 5 and Table 6. The BH curves are also depicted in Figures 2 and 3.

Table 5 Physical and mechanical properties of DW315_50 [28]

Parameter	Value	Units
Thermal conductivity	35	W/m*K
Resistivity	54	μΩm
Core loss at 1.5T 50 Hz	2.7	W/kg
Tensile strength	534	MPa
Young's modulus	210	GPa

Table 6 Physical and mechanical properties of Somaloy 700HR-5P [29]

Parameter	Value	Units
Thermal conductivity	21	W/m*K
Resistivity	700	μΩm
Core loss at 1.5T 50 Hz	6.6	W/kg
Tensile strength	20	MPa
Young's modulus	150	GPa

Although the core loss of Somaloy at 1.5T and 50Hz is higher, it remains relatively stable and does not increase significantly even at higher frequencies. [29] [30]

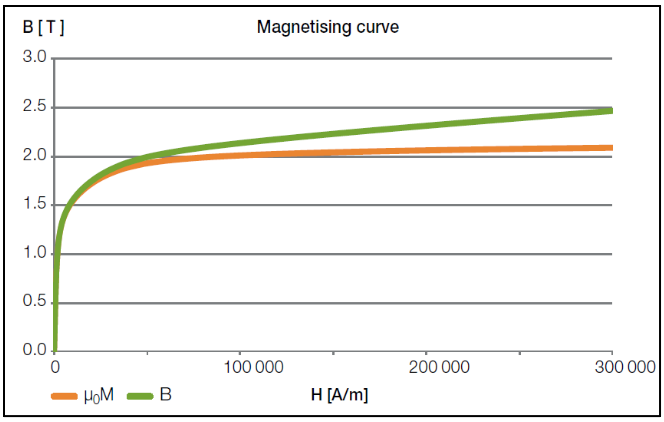

Fig. 2 BH curve of Somaloy 700HR-5P [29]

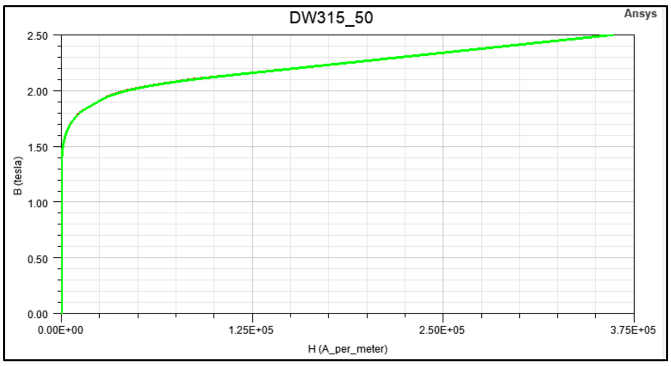

Fig. 3 BH curve of DW315_50 [27]

3 Methodology

The induction motor is analysed using the finite element analysis method with the help of the software ANSYS Electronics Desktop 2022 R1. The flowchart in Figure 4 delineates the process precisely.

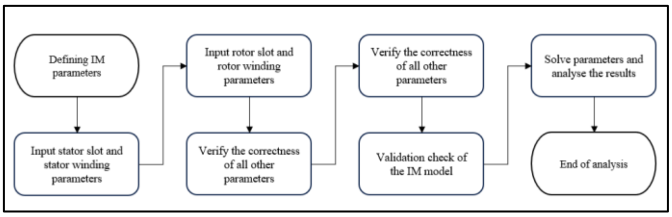

Fig. 4 Flowchart depicting the analysis process in ANSYS

ANSYS Electronics Desktop 2022 R1 offers a wide variety of modules to simulate different conditions and electrical machines. In this study, RMxprt and Maxwell 2D modules are used to simulate the induction motor. Firstly, the appropriate electrical machine is selected under the RMxprt module to start the simulation. Then the motor parameters of the proposed three-phase induction motor are inputted in the software. Furthermore, the necessary parameters of the rotor slots, rotor winding, stator slots, stator winding, stator type and rotor type are programmed into the software. These parameters are tabulated in Tables 7-14.

Table 7 Parameters of the induction motor [27]

Parameter	Value	Units
Machine type	Three phase induction motor	type
Number of poles	4	count
Stray loss factor	0.01	-
Frictional loss	40	W
Windage loss	15	W
Reference speed	1450	rpm

Table 8 Parameters of the stator of the induction motor [27]

Parameter	Value	Units
Outer diameter	210	mm
Inner diameter	135	mm
Length	134	mm
Stacking factor	0.95	-
Steel type	DW315_50 / Somaloy 700HR-5P	type
Number of slots	36	count
Slot type	2	type
Lamination sectors	1	count
Press board thickness	0	mm
Skew width	0	mm

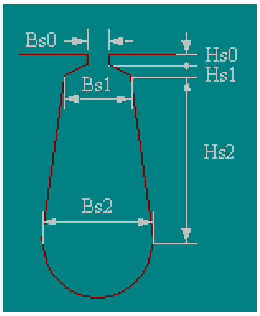

Fig. 5 The slot shape and dimensions of the stator

Table 9 Parameters of the stator slot of the induction motor [27]

Parameter	Value	Units
Hs0	1	mm
Hs1	0.8	mm
Hs2	11.8	mm
Bs0	3	mm
Bs1	6	mm
Bs2	8	mm

Table 10 Parameters of the stator winding of the induction motor [27]

Parameter	Value	Units
Winding layers	1	count
Winding type	Whole-coiled	type
Parallel branches	1	count
Conductors per slot	41	count
Number of strands	1	count
Wire wrap	0.06	mm
Wire diameter	Ø1.18	mm

Table 11 Parameters of the stator end insulation of the induction motor [27]

Parameter	Value	Units
Input half-turn length	-	-
End extension	0	mm
Base inner radius	0	mm
Tip inner diameter	0	mm
End clearance	0	mm
Slot liner	0.32	mm
Wedge thickness	2.5	mm
Layer insulation	0	mm
Limited fill factor	0.75	-

After feeding all the necessary values of the stator into the software, it displays a model of the stator with the magnetic flux lines as shown in Figure 6.

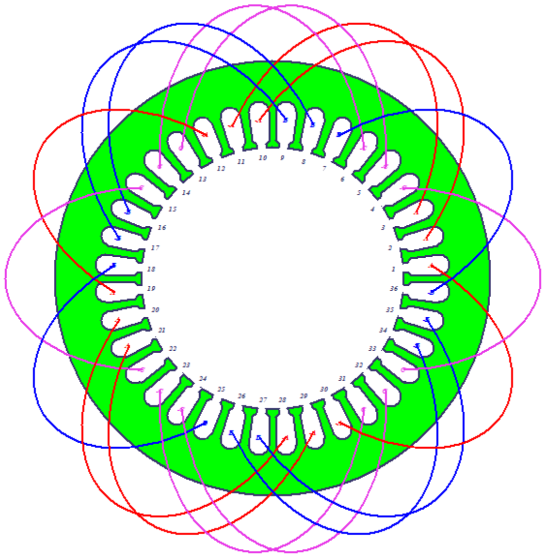

Fig. 6 Image of the created stator on ANSYS Electronics

Table 12 Parameters of the rotor of the induction motor [27]

Parameter	Value	Units
Stacking factor	0.95	-
Number of slots	26	count
Slot type	2	type
Outer diameter	134	mm
Inner diameter	48	mm
Length	134	mm
Steel type	DW315_50	type
Skew width	1	mm
Cast rotor	Yes	-

Table 13 Parameters of the rotor slot of the induction motor [27]

Parameter	Value	Units
Hs0	1	mm
Hs01	0	mm
Hs1	1.4	mm
Hs2	16.2	mm
Bs0	1	mm
Bs1	4.4	mm
Bs2	4.4	mm

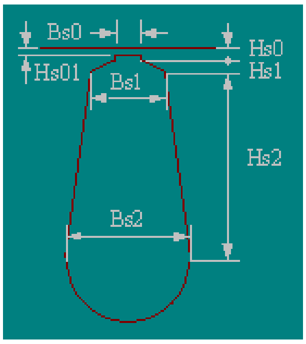

Fig. 7 The slot shape and dimensions of the rotor

Table 14 Parameters of the rotor winding of the induction motor [27]

Parameter	Value	Units
Bar conductor type	Copper or aluminium	type
End length	0	mm
End ring width	11.2	mm
End ring height	12	mm
End ring conductor type	Copper or aluminium	type

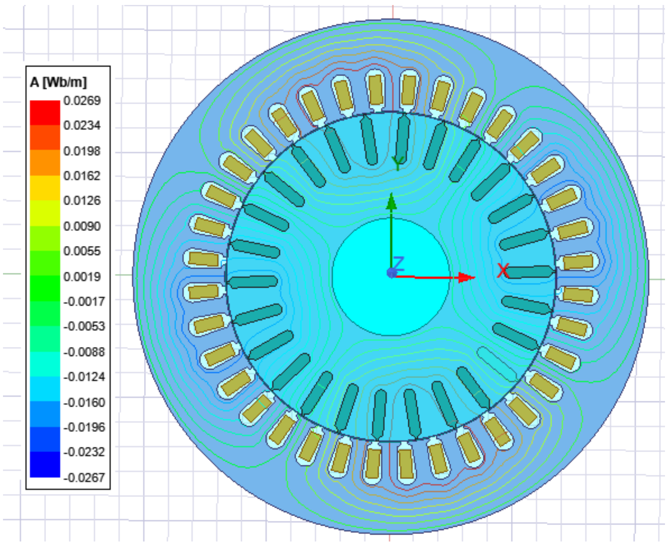

Fig. 8 Image of the created stator-rotor interface with magnetic flux lines

As shown in Figure 8, the stator and the rotor models are generated with the desired specifications and dimensions. The model is then validated using the validation check feature and simulated to obtain the solution suite and various performance curves.

4 Results

The simulations results showed that Somaloy 700HR-5P outperformed its counterpart in many aspects, but has also underperformed in some.

A stark difference was observed in the torque versus speed curve, where Somaloy delivered a torque of 122 Nm against 105 Nm, the torque from the DW315_50 motor. A 16% increase in the delivered torque differentiates this motor well considering the application of this motor in industrial conveyors. Figures 9 and 10 depict the torque-speed curves of the two types of motors.

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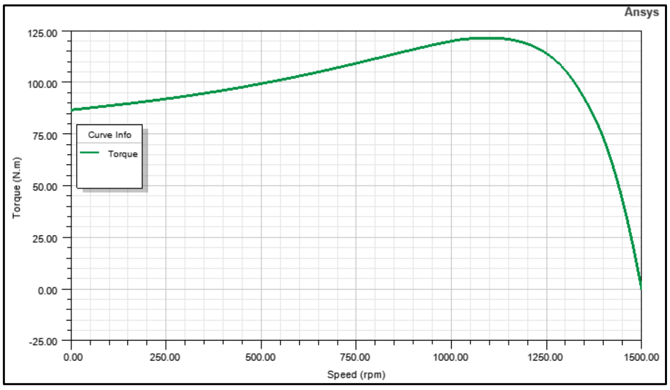

Fig. 9 The torque-speed curve of Somaloy 700HR-5P motor

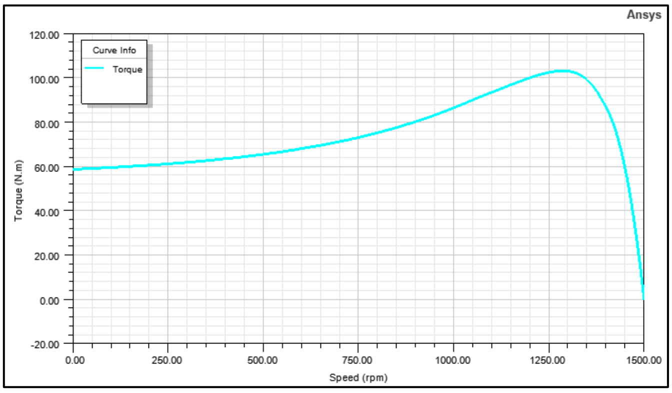

Fig. 10 The torque-speed curve of the DW315_50 motor

The output power delivered by the proposed motor as opposed to the conventional motor is also much higher as displayed in Figures 11 and 12.

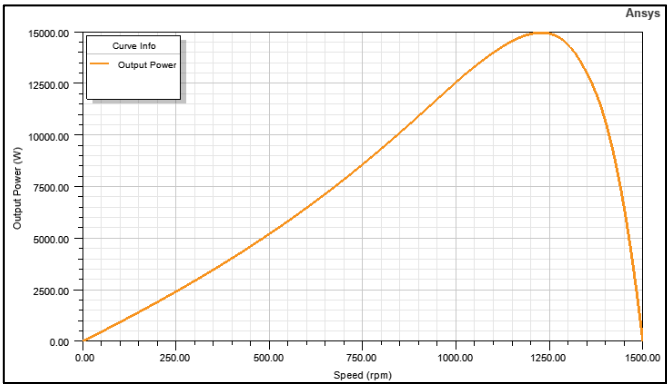

Fig. 11 The output power-speed curve of Somaloy 700HR-5P

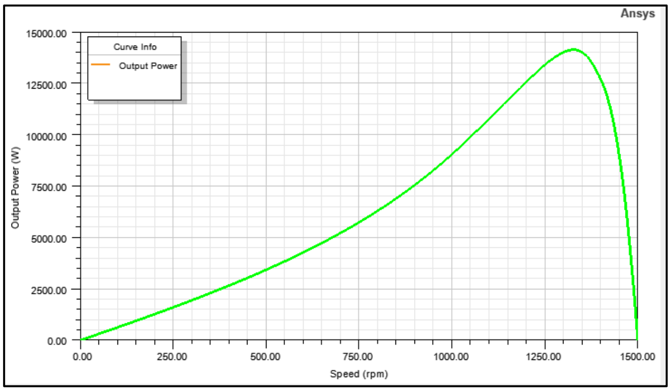

Fig. 12 The output power-speed curve of DW315_50 motor

An efficiency comparison of the two motors show that there is only a difference of 0.99%. Figures 13 and 14 show the efficiency-speed curves of the two motors.

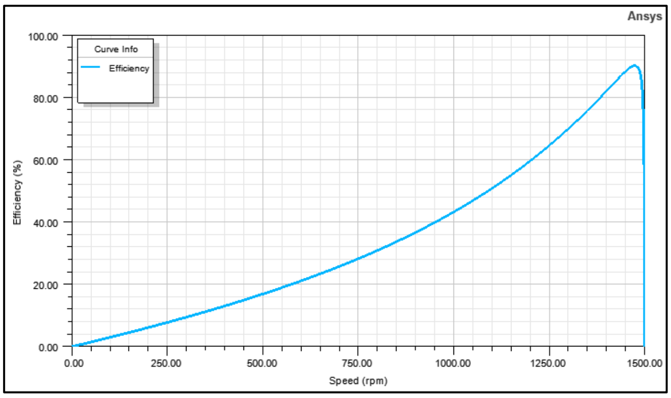

Fig. 13 The efficiency-speed curve of Somaloy 700HR-5P

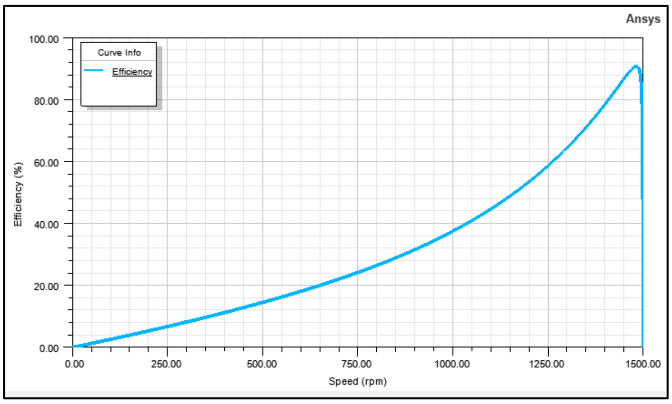

Fig. 14 The efficiency-speed curve of the DW315_50 motor

When the power factors of both the motors are compared, the Somaloy 700HR-5P underperforms with a power factor of 0.76 as opposed to 0.84 from the DW315_50 motor. Figures 15 and 16 show the power factor-speed curves of the compared motors.

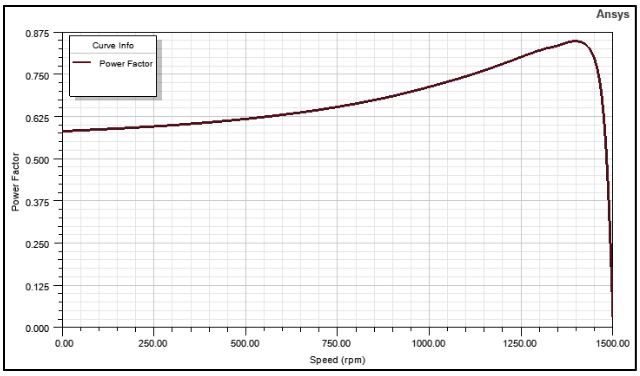

Fig. 15 The power factor-speed curve of Somaloy 700HR-5P

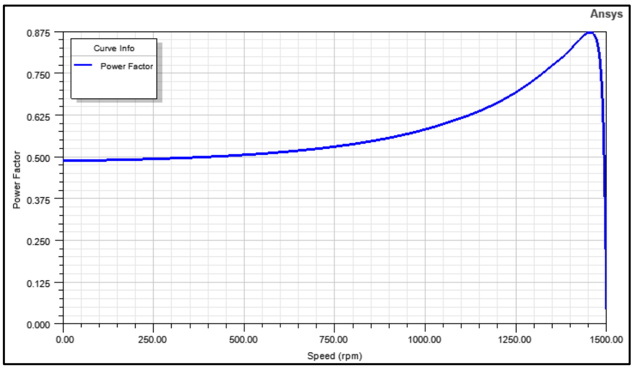

Fig. 16 The power factor-speed curve of DW315_50 motor

Furthermore, because the density of aluminium is lighter than copper, the rotor bar material weight is just 0.78 kg compared to the DW315_50's counterpart weight at 2.60 kg. This aspect enables the use of lightweight industrial conveyor motors by reducing the overall weight of the motor by 2.25 kg. The harmonic leakage reactance is also halved in the Somaloy 700HR-5P motor at 0.677 ohm compared to 1.066 ohm from the DW315_50 motor. The locked rotor torque of the Somaloy 700HR-5P motor is 86.618 Nm and it is 58.651 Nm for the other motor. A higher locked rotor torque is an ideal outcome for this specific application because of the higher load requirements during start-up. A comparison between the key performance parameters of the motors is shown in Table 15. [31] [32]

Table 15 The simulation results of the key parameters of motor

Parameter	Somaloy/ Aluminium	DW315/ Copper	Units
Rotor bar material density	2689	8933	kg/m^3
Rotor bar material weight	0.783	2.60	kg
Total net weight	30.245	32.491	kg
Harmonic leakage reactance	0.677	1.066	ohm
Iron core loss	0.003	71.24	W
Efficiency	89.25	90.24	%
Locked rotor torque	86.618	58.651	Nm

5 Conclusion

The simulation results indicate that the proposed materials, Somaloy 700HR-5P and Aluminium show propitious performance parameters. Somaloy 700HR-5P offers tremendous benefits on both sides, performance-wise and sustainability-wise. Aspects such as high recyclability, lesser carbon emissions in material production, higher lifetime will help manufacturers in moving towards the goal of carbon neutrality while also maintaining superior performance of the motor. Although the cost of Somaloy 700HR-5P is higher than conventional steel used in electrical appliances, the benefits obtained are multi-fold. Other advantages such as the reduced weight of the rotor cage, higher torque delivered, high power delivered, and similar efficiency make the motor with these proposed materials an optimal choice for usage in three phase induction motors used in industrial conveyors.

6 Acknowledgements

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7 References

[1] Omri Wallach, Race to Net Zero: Carbon Neutral Goals by Country, Visual Capitalist, 2022

[2] GMI (Global Market Insight), report GMT12800,2024

[3] London Metal Exchange (LME) “2023 Annual Average Price Report: Aluminium Alloy 6061 (European Warehouse)”. London, UK, 2023

[4] Höganäs AB. “Technical Datasheet: Somaloy® 5P (Bulk OEM Pricing 2023)”. Höganäs, Sweden. 2023.

[5] CRU Group. “European Electrical Steel Market Report 2023: Cold-Rolled Non-Oriented Grades”. London, UK, 2023.

[6] International Aluminium Institute (IAI). “Global Aluminium Recycling Rates: End-of-Life Statistics 2022”. London, UK, 2022.

[7] Höganäs AB. “Sustainability Report 2023: Closed-Loop Recovery Rates for Somaloy Composites”. Höganäs, Sweden, 2023.

[8] EUROFER. “European Steel Recycling Standards: Electrical Steel Grades”. Brussels, Belgium, 2023.

[9] European Aluminium. “Circular Economy Report 2023: Post-Consumer Recycling Cost Benchmarks”. Brussels, Belgium, 2023.

[10] SMaRT@UNSW. “Industrial Material Recovery Cost Estimates: Soft Magnetic Composites”. Sydney, Australia, 2022.

[11] International Aluminium Institute (IAI). *“Global Life Cycle Inventory Data for Aluminium Production.”* 2022. (Industry Report)

[12] IEEE/IEC Joint Working Group. “Standardized Accelerated Life Testing for Induction Motors (2019-2023 Data)”. IEEE Transactions on Industry Applications, Vol. 57, No. 4. 2021.

[13] EPRI (Electric Power Research Institute). “Case Studies on High-Efficiency Steel Laminations in Industrial Motors (2018-2022)”. EPRI Report No. 3002022729. Palo Alto, CA, 2022.

[14] Höganäs AB. *“Energy Consumption in Somaloy® Manufacturing: A Comparative Study.”* Sweden, 2021. (Technical Report)

[15] European Steel Association (EUROFER). *“Energy Use in Electrical Steel Production.”* Brussels, 2023. (Industry Report)

[16] World Aluminium. *“Carbon Footprint of Primary Aluminium Smelting.”* 2023. (White Paper)

[17] Lindblad, J. et al. *“CO_2 Emissions in Soft Magnetic Composite Production.” Journal of Sustainable Materials*, vol. 15, 2022. (Peer-Reviewed Article)

[18] International Energy Agency (IEA). *“Emissions from Electrical Steel Processing.”* Paris, 2023.

[19] European Aluminium. *“Recycling Aluminium: Energy Savings and Emissions Reduction.”* 2021. (Industry Report)

[20] Höganäs AB. *“Life Cycle Assessment of Somaloy® Recycling.”* Sweden, 2020.

[21] Steel Recycling Institute (SRI). *“Energy Efficiency in Steel Scrap Processing.”* 2022.

[22] U.S. Geological Survey (USGS). *“Aluminium Recycling Rates and Environmental Impact.”* 2023. (Government Report)

[23] European Powder Metallurgy Association (EPMA). *“Sustainability of SMC Materials.”* 2021. (Industry Report)

[24] ‘Specification Guide Electric Motors’, https://static.weg.net/medias/downloadcenter/ha0/h5f/WEG-motors-specification-of-electric-motors-50039409-brochure-english-web.pdf, accessed 9 July 2025

[25] Boldea, I.: 'Induction Machines Handbook Transients, Control Principles, Design and Testing' (CRC Press, 2020, 3rd edition)

[26] Umans, S.D.: 'Electric Machinery' (McGraw-Hill, 2014, 7th edition)

[27] Li, Q.: 'ANSYS Simulation Design Course Handbook' (Shanghai Dianji University, 2025)

[28] 'Electrical Steel Sheets', https://www.jfe-steel.co.jp/en/products/electrical/catalog/f1e-001.pdf, accessed 10 July 2025

[29] 'Somaloy 5P Material Data', https://www.hoganas.com/globalassets/downloads/libary/somaloy_somaloy-5p-material-data_2274hog.pdf, accessed 10 July 2025

[30] A. R. Asari, Y. Guo and J. Zhu.: 'Performances of SOMALOY 700 (5P) and SOMALOY 500 Materials under 1-D Alternating Magnetic Flux Density' 2019 International UNIMAS STEM 12th Engineering Conference (EnCon), Kuching, Malaysia, 2019, pp. 52-58

[31] Najgebauer, M., Szczygłowski, J., Ślusarek, B., et al.: 'Magnetic Composites in Electric Motors' In: Mazur, D., Gołębiowski, M., Korkosz, M. (eds): 'Analysis and Simulation of Electrical and Computer Systems Lecture Notes in Electrical Engineering', (Springer Nature, 2018, vol 452, Cham.)

[32] Hamler, A., Goričan, V., Šuštaršič, B.: 'The use of soft magnetic composite materials in synchronous electric motor', Journal of Magnetism and Magnetic Materials, 2006, Volume 304, Issue 2, pp e816-e819,