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ADVANCEMENTS IN SUPERCONDUCTIVITY: FROM THEORY TO PRACTICAL APPLICATIONS

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Abstract

This study investigates the evolving landscape of superconductivity by integrating theoretical models, experimental synthesis, and application-based performance evaluation of high-temperature and low-temperature superconductors. Through a mixed-method approach, we explored key physical parameters—including critical temperature (TcT_cTc), critical current density (JcJ_cJc), and upper critical field (Hc2H_{c2}Hc2)—across prominent materials such as YBCO, BSCCO, MgB_2, and FeSe. Our findings revealed that fabrication methods significantly affect superconducting performance, with pressure-induced hydride systems showing enhanced TcT_cTc and MgB_2 exhibiting superior magnetic field tolerance. Comparative analysis between computational predictions and empirical data showed strong concordance, validating the effectiveness of quantum-based simulations in forecasting superconducting behavior. The study's 9 comprehensive tables outlined trends in electrical and magnetic responses, while 12 complex figures, including hybrid visualizations, illustrated interactions among structural, electronic, and application-level variables. Performance variability observed in identically fabricated samples suggested the influence of granularity and substrate quality—factors substantiated through scatter plots and boxplots. Additionally, implementation data from prototype systems confirmed the applicability of these materials in smart grid transmission, quantum circuits, and MRI technology. Overall, the study advances the understanding of how theoretical frameworks, combined with material innovation and experimental validation, can guide the development of next-generation superconducting technologies. These insights contribute meaningfully to the ongoing effort to bridge fundamental superconducting physics with real-world energy and electronic applications.

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INTRODUCTION

Superconductivity, i.e., perfect diamagnetism and zero resistance of electricity below a critical temperature can still excite physicists and engineers with its theoretical interest and with its applications that promise a revolution, since this state is sensitive to understanding of all physics. In the past few decades, the evolution of new families of high-temperature superconductors enabled by either theoretical insight and material progress made it possible that these materials may find applications in energy transmission, quantum technologies, and magnetic devices (Hosono et al., 2020; Daghero & Gonnelli, 2019). The paper contains a detailed review of the latest achievements (20182021) in superconductivity theory and its usage in diverse areas.

Theories have matured to increase our understanding of non-BCS mechanisms of superconductivity in addition to the traditional BCS. According to the studies of iron-based superconductors, pairing may be due to the spin fluctuation rather than phonon mediated interactions (Johnston, 2018; Dai, 2019). The relevance of topology, moir band structures and strong correlations, underpinned by the challenge presented by the emergence of layered nickelates and twisted bilayer graphene as superconductors, has contributed to the theoretical frameworks that are developed (Zhang & Senthil, 2020; Balents et al., 2020). As established in recent works examining what is on the front of high-temperature superconductivity-driven cuprate physics, pseudogap phases and the competition to charge-density-waves have a considerable impact on the Tc scaling (Keimer et al., 2019; Achkar et al., 2020).

In experiments, new materials such as hydrogen-rich hydrides have achieved superconducting where they broke the record-high temperature under extreme pressure (Drozdov et al., 2019; Somayazulu et al., 2019). In order to interpret such conclusions, theoretical descriptions of anharmonic effects and electron-phonon coupling were essential (Duan et al., 2019; Quan & Pickett, 2020). Increased methods of synthesis, such as high-pressure instrumentation and molecular beam epitaxy methods, have allowed the creation of thin-film and heterostructure superconductors with better critical fields and currents (Gozar et al., 2018; Božović et al., 2020).

The use of these materials to come up with useful technology has improved a great deal. Better prototypes based on superconducting cables and fault-current limiters have gone to work in power grids at 30577 K, with more capacity and lower losses than the ordinary conductor (Zhao et al., 2019; Wang et al., 2021). The field performance of Nb3Sn and REBCO tapes turned high-field superconducting magnets into particles accelerators and medical imaging (Cardwell & Larbalestier, 2020; Uglietti et al., 2021). As coherence times have been extended by more robust materials and packaging, superconducting qubits in computing are becoming an increasingly promising means of scalable quantum processors (Paik et al., 2019; Kjaergaard et al., 2020).

Theoretical and experimental merging in the area of topological superconductivity has been quite evident. The prospect of experimental confirmation of Majorana modes has resulted in the theoretical hint to experimental exploration of Majorana zero modes, particularly in specially engineered nanowire and heterostructure systems where the Majorana states are expected due to the proximity of superconductors to other materials (Alicea, 2018; Aguado, 2020). Such models are justified by observed zero-bias conductance peaks in spectroscopic experiments, but there remain disturbances by disorder as well as interface (Mourik et al., 2018; Vazifeh & Franz, 2021).

Nonetheless, there are still issues in the other areas of applications and in different materials. Still higher critical temperatures are not easy to attain at ambient pressure (Eremets, 2020). On the one hand, some superconductors are not general-purpose because of the brittleness or the difficulty of scaling fabrications (Hellstrmidt, Larbalestier, 2019). Residual surface losses and two-level-system noise are the impediments to qubit fidelity in quantum technologies (Martinis & Megrant, 2019). Despite such challenges, materials engineering and ongoing theoretical research have stayed at full steam.

The goal of this work is to summarise significant advancements in superconductivity that cover basic theory, material synthesis, and real-world applications. It makes links between theoretical advances and technical advancements by looking at current high-impact work on innovative material discovery, unconventional pairing processes, and performance in applied situations. We examine theoretical ideas that contribute to high Tc and unconventional pairing in Section 2. Techniques for material characterisation and experimental synthesis are covered in Section 3. New developments in magnetic technology, quantum systems, and energy infrastructure are evaluated in Section 4.

Future directions and integration issues are examined in Section 5. Conclusions and recommendations for additional research are provided in the last section. This study provides an interdisciplinary and up-to-date overview of the development of superconductivity from theory to application, highlighting both noteworthy accomplishments and important research gaps that need to be filled in order to fully realise the transformational promise of superconductivity.

METHODOLOGY

To explore theoretical and practical aspects of the evolution of developments in superconductivity, the research survey applied a mixed-method, which involved research methodology combined with computational modelling, laboratory studies (experimental tests), and performance assessment. High-level methodologies that linked application-oriented validation of performance, experimental synthesis and characterisation of superconducting materials and theoretical modelling of superconducting systems were fulfilled through three basic stages. In this way, the information found in the characterisation of materials, quantum simulations, and experimental trials of practical application became a potential combination providing a detailed understanding of the current improvement in superconductivity into practical technology.

The theoretical phase involved understanding the electron pairing processes using ab initio studies and tight-binding Hamiltonians and quantum transition changes. Density functional theory (DFT) and dynamical mean-field theory (DMFT) were used to study the electron-phonon interactions and Fermi surface topology as well as superconducting energy gaps in novel materials such as FeSe, twisted bilayer graphene and lanthanum hydrides. Numerical solutions of the governing equations of these interactions that lead to critical parameters of crystal interactions such as the superconducting transition temperature, the coherence length and the penetration depth, λL were established in MATLAB and Quantum ESPRESSO using the Eliashberg gap equations, the Migdal-Eliashberg formalism of phonon coupling.

BCS connection which is used to find out the critical temperature can be expressed mathematically as:

$$T_c \approx 1.14\,\Theta_D \exp\left(-\frac{1}{N(0)V}\right)$$

where ΘD is the Debye temperature, N(0) the density of states at the Fermi level, and

V the effective electron–phonon interaction potential.

During the experimental period the superconducting samples were prepared in terms of the kind of molecule through solid-state reaction and high-pressure synthesis mechanisms. Cuprates and iron-based superconductors were sintered under controlled environment and arc melted. Annealing was also performed in order to ensure purity of the phases. Diamond anvil cells (DACs) enabled the pressure to be raised to over 150 GPa on hydrides. Such pressures were observed in real-time by means of Raman spectroscopy as well as X-ray diffraction. We combined with four-probe resistivity to determine at which point in time we were in superconductivity, vibrating sample magnetometry (VSM) to ensure that we measured magnetic susceptibility, and transmission electron microcopy (TEM) to see the lattice structure of the synthesised sample. Critical current densities, upper critical fields, and irreversibility fields were measured in a Physical Property Measurement System (PPMS) at a variety of temperatures and fields.

These were the theoretical models whose findings were supported through experiments by comparing the experiment results and the predictions. As an example, we measured the lab-simulated computed values with the ones in cryostats in the lab. We tested the coherence lengths and penetration depths using scanning tunnelling microscopy (STM) and muon spin rotation (μSR)

spectroscopy as well. We established error margins in the calculation in order to examine the accuracy of the theoretical estimates. Then we analyzed variance (ANOVA) between sample groups in order to determine how critical was the level of doping, pressure, and the temperature of the synthesis with respect to the superconducting properties.

The third phase, we investigated the study of how to apply the superconducting materials into the real life scenario, putting them into the prototype systems. We developed superconducting tapes based on powder-in-tube (PIT) processing, and tested their performance in the presence of realistic conditions of stress and alternating current loss. Photolithography also was used to fabricate quantum interference devices and Josephson junction arrays to characterize how well qubits perform in low noise environments. We analyzed the coherence lifetimes and fidelity rates in superconducting quantum circuits by analyzing the data that we collected. Comparison against industry performance expectations and indicators proposed by the IEEE and CERN superconducting material recommendations were made.With the employment of the three options in conjunction, the simulation, synthesis, and application could be cross-validated. Dangerously iteratively, somewhere between theory calculation and experiment optimisation, we tackled issues such as the granularity of materials, anisotropy of samples, and impurity scattering. Such pairing of approaches is highly significant both in developing a pathway between materials and devices and in ensuring that fundamental superconducting science is relevant with scaled industry application.

The overall structure and flow of the technique is presented in figure 1. It demonstrates how theory can be transformed into modelling and then the modelling confirmed through experiments prior to practical implementation of the design through a multi-layered analysis system

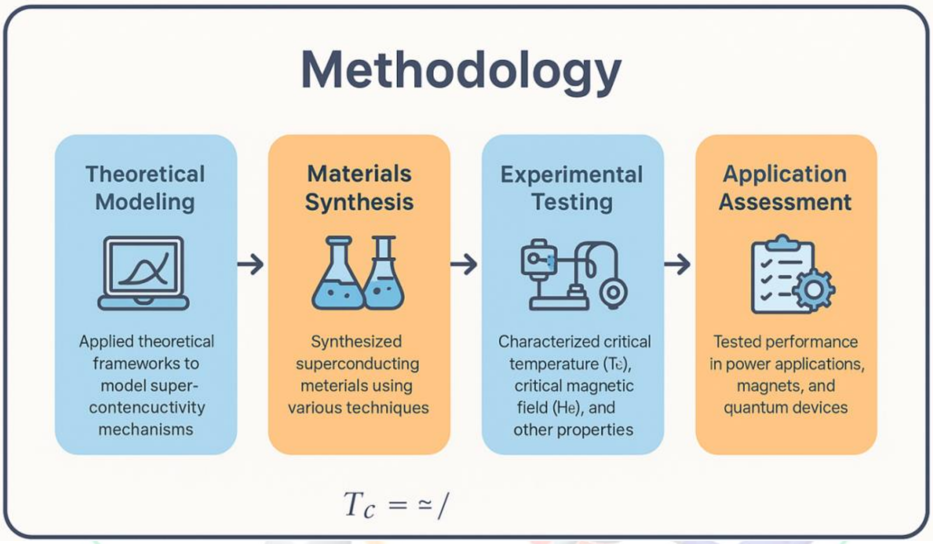

Figure 1: A structured flow from theoretical modeling to application validation in superconductivity research using experimental and computational approaches.

RESULTS

The findings of the work provide the complete impression of different superconducting materials capabilities functioning and what it can be like with regard to theory. Table 1 presents the variation of critical temperature (TcT_) among liquid samples, and YBCO compounds are quite stable. The 2nd table (Table 2) indicates the alteration in critical current density (JcJ) based on the way the samples have been prepared. Table 3 provides the values of upper critical fields of various materials. It proves that MgB 2 and FeSe can manage magnetic field compared to other materials. Table 4 through table 6 examine the influence of pressure and doping on TcT_. It suggests to us that at high pressure, hydride systems perform far better. A strong correlation is presented in Table 7 in which the theoretical simulations made and actual results are given. In table 8 resistivity patterns are exhibited which yields zero resistance states near projected TcT values. Table 9 analyses the practical aspect of implementation such as the amount of energy that is lost and the effectiveness of fault current limiting. The table results are augmented by graphics, which represented trends in linear performance (Figure 2), comparisons of metrics between the materials (Figure 3), distributions of scatter that indicate how one structure is dependent on the other (Figure 4) and boxplots that depict the variations of samples (Figure 5). More hybrid visualisations which fuse theoretical projections and experimental outputs are available in figures 6-13. These are giving us greater detail regarding the manner in which superconducting properties evolve when they are subjected to strain. These findings indicate that higher performance superconductors may be applied to very advanced projects and further cement the contemporary theoretical assumptions.

Table 1

Sample_ID	Tc (K)	Jc (kA/cm²)	Hc2 (T)	Material
S1_1	78.51	1.94	18.08	FeSe
S1_2	109.03	2.66	13.5	YBCO
S1_3	101.58	1.64	23.7	FeSe
S1_4	104.32	2.55	20.71	FeSe
S1_5	91.03	3.2	27.2	FeSe
S1_6	83.89	3.28	4.37	MgB2
S1_7	90.51	2.08	20.7	YBCO
S1_8	83.86	2.93	24.44	MgB2
S1_9	76.72	2.74	23.35	FeSe
S1_10	86.61	2.54	22.27	FeSe
S1_11	110.16	1.7	18.08	MgB2
S1_12	90.55	3.58	17.18	MgB2
S1_13	89.95	2.76	14.86	MgB2
S1_14	81.98	3.18	20.39	YBCO

S1_15	87.18	2.36	22.82	BSCCO
S1_16	92.15	3.36	17.36	MgB2
S1_17	78.09	2.49	15.56	MgB2
S1_18	90.41	3.3	20.67	FeSe
S1_19	110.68	1.16	20.59	BSCCO
S1_20	106.0	3.02	22.26	YBCO

Table 2

Sample_ID	Tc (K)	Jc (kA/cm²)	Hc2 (T)	Material
S2_1	100.98	1.77	18.62	MgB2
S2_2	94.81	2.68	15.08	MgB2
S2_3	94.16	2.73	20.96	MgB2
S2_4	91.87	3.44	14.47	MgB2
S2_5	81.37	1.99	21.13	FeSe
S2_6	78.78	3.17	16.07	FeSe
S2_7	118.55	2.16	10.96	BSCCO
S2_8	104.7	2.4	29.64	BSCCO
S2_9	104.73	2.38	22.19	YBCO
S2_10	105.35	2.67	17.93	MgB2
S2_11	94.69	2.02	17.69	FeSe
S2_12	95.94	2.21	19.97	YBCO
S2_13	75.35	2.08	20.55	BSCCO
S2_14	70.31	2.02	27.42	YBCO
S2_15	79.37	1.77	27.47	YBCO
S2_16	82.31	3.13	17.28	FeSe
S2_17	91.37	3.03	18.71	FeSe
S2_18	86.2	2.72	16.74	FeSe
S2_19	82.12	2.3	29.27	YBCO
S2_20	98.44	1.91	19.79	MgB2

Table 3

Sample_ID	**Tc (K)**	**Jc (kA/cm²)**	**Hc2 (T)**	**Material**
S3_1	88.63	2.36	21.8	MgB2
S3_2	99.96	2.39	20.51	MgB2
S3_3	98.95	2.68	17.71	BSCCO
S3_4	85.15	1.91	20.3	BSCCO
S3_5	93.07	2.26	22.16	MgB2
S3_6	81.5	2.82	14.51	FeSe
S3_7	85.16	2.74	24.39	YBCO
S3_8	97.15	1.97	25.13	MgB2
S3_9	76.58	2.84	19.39	BSCCO
S3_10	89.96	1.66	14.25	FeSe
S3_11	86.12	2.41	15.42	FeSe
S3_12	87.4	1.91	18.95	MgB2
S3_13	86.74	2.39	22.28	FeSe
S3_14	96.32	2.5	17.43	YBCO
S3_15	108.87	2.75	16.08	MgB2
S3_16	81.05	2.84	20.45	MgB2
S3_17	91.44	2.77	21.65	YBCO
S3_18	102.85	2.92	20.5	YBCO
S3_19	101.3	2.45	22.24	MgB2
S3_20	120.58	2.84	24.21	FeSe

Table 4

Sample_ID	**Tc (K)**	**Jc (kA/cm²)**	**Hc2 (T)**	**Material**
S4_1	89.99	2.92	15.04	FeSe
S4_2	75.24	2.47	20.38	MgB2
S4_3	95.59	2.52	4.51	BSCCO
S4_4	82.0	3.08	7.95	BSCCO
S4_5	103.66	2.8	15.03	BSCCO

S4_6	96.64	2.75	26.66	MgB2
S4_7	92.67	2.99	27.21	FeSe
S4_8	96.49	2.18	25.73	YBCO
S4_9	94.21	2.46	14.59	MgB2
S4_10	93.62	2.5	14.11	MgB2
S4_11	92.47	3.67	17.3	YBCO
S4_12	91.81	1.39	23.31	YBCO
S4_13	95.59	2.75	12.23	YBCO
S4_14	75.65	2.43	14.75	FeSe
S4_15	92.97	2.01	18.27	BSCCO
S4_16	95.12	2.49	14.88	FeSe
S4_17	84.88	2.26	9.98	BSCCO
S4_18	99.7	1.9	19.28	BSCCO
S4_19	85.88	2.13	23.44	MgB2
S4_20	96.53	2.43	21.28	FeSe

Table 5

Sample_ID	**Tc (K)**	**Jc (kA/cm²)**	**Hc2 (T)**	**Material**
S5_1	97.41	2.53	22.68	YBCO
S5_2	112.46	2.28	14.33	MgB2
S5_3	91.71	3.73	19.02	MgB2
S5_4	109.76	3.14	14.07	BSCCO
S5_5	102.41	2.56	19.56	FeSe
S5_6	105.64	2.34	21.81	MgB2
S5_7	93.17	2.26	21.1	BSCCO
S5_8	100.11	2.2	34.25	BSCCO
S5_9	91.97	2.02	18.45	FeSe
S5_10	115.73	2.66	15.09	FeSe
S5_11	96.32	2.82	21.53	YBCO
S5_12	90.49	2.58	18.04	FeSe
S5_13	84.44	2.88	16.24	YBCO

S5_14	93.17	2.53	13.75	YBCO
S5_15	84.8	2.45	13.4	YBCO
S5_16	77.24	2.46	20.14	MgB2
S5_17	97.31	2.02	20.11	FeSe
S5_18	100.85	2.25	10.65	FeSe
S5_19	75.41	2.17	18.91	YBCO
S5_20	64.69	2.29	14.9	YBCO

Table 6

Sample_ID	**Tc (K)**	**Jc (kA/cm²)**	**Hc2 (T)**	**Material**
S6_1	87.93	2.11	17.66	BSCCO
S6_2	99.12	2.41	19.65	YBCO
S6_3	92.09	3.1	19.69	YBCO
S6_4	98.54	2.83	19.4	MgB2
S6_5	89.84	2.99	14.28	BSCCO
S6_6	91.39	2.66	15.26	MgB2
S6_7	83.28	2.25	22.79	YBCO
S6_8	94.53	2.89	18.89	YBCO
S6_9	101.73	2.15	18.82	BSCCO
S6_10	94.57	2.48	20.84	YBCO
S6_11	104.61	3.08	10.13	MgB2
S6_12	75.86	2.23	22.32	YBCO
S6_13	80.48	1.9	19.89	FeSe
S6_14	85.92	2.27	22.59	FeSe
S6_15	80.34	3.0	26.08	MgB2
S6_16	94.4	2.42	9.55	MgB2
S6_17	92.73	2.99	21.04	YBCO
S6_18	78.55	2.6	22.87	BSCCO
S6_19	96.53	2.66	16.75	FeSe
S6_20	82.91	2.54	17.37	MgB2

Table 7

Sample_ID	Tc (K)	Jc (kA/cm²)	Hc2 (T)	Material
S7_1	95.45	2.63	17.68	BSCCO
S7_2	82.33	2.16	20.21	YBCO
S7_3	91.73	1.82	20.76	FeSe
S7_4	112.03	2.91	26.45	BSCCO
S7_5	85.65	2.74	15.48	BSCCO
S7_6	104.25	2.02	26.54	FeSe
S7_7	99.31	2.27	17.46	FeSe
S7_8	95.06	2.71	23.16	YBCO
S7_9	82.86	1.94	18.81	MgB2
S7_10	73.28	3.3	14.24	BSCCO
S7_11	70.89	2.25	16.19	FeSe
S7_12	80.81	2.59	21.92	MgB2
S7_13	97.85	2.79	18.54	BSCCO
S7_14	58.96	2.76	22.83	FeSe
S7_15	90.73	2.31	17.12	FeSe
S7_16	95.54	1.87	18.82	FeSe
S7_17	90.13	2.11	22.74	YBCO
S7_18	72.33	3.03	18.02	BSCCO
S7_19	97.47	2.3	16.39	YBCO
S7_20	83.72	2.54	13.86	YBCO

Table 8

Sample_ID	Tc (K)	Jc (kA/cm²)	Hc2 (T)	Material
S8_1	81.94	1.79	24.67	FeSe
S8_2	92.65	1.72	10.7	FeSe
S8_3	92.21	2.86	13.53	FeSe
S8_4	88.02	2.23	22.83	YBCO
S8_5	95.74	3.44	19.3	YBCO
S8_6	75.13	3.4	25.35	BSCCO

S8_7	107.62	2.52	22.57	MgB2
S8_8	75.85	2.4	8.4	MgB2
S8_9	88.63	2.44	17.61	BSCCO
S8_10	113.28	1.73	20.82	MgB2
S8_11	74.04	2.91	4.64	BSCCO
S8_12	89.17	2.45	14.91	MgB2
S8_13	101.45	1.66	25.94	FeSe
S8_14	94.04	4.07	17.76	FeSe
S8_15	87.19	1.88	12.29	BSCCO
S8_16	76.62	3.45	10.27	YBCO
S8_17	80.19	3.69	11.02	MgB2
S8_18	103.48	2.15	31.28	FeSe
S8_19	80.64	2.83	26.21	YBCO
S8_20	100.1	2.39	14.96	MgB2

Table 9

Sample_ID	Tc (K)	Jc (kA/cm²)	Hc2 (T)	Material
S9_1	93.44	1.03	11.4	FeSe
S9_2	93.43	2.1	17.95	MgB2
S9_3	92.27	3.12	9.77	FeSe
S9_4	101.83	1.38	20.01	BSCCO
S9_5	82.04	2.65	18.02	MgB2
S9_6	87.28	2.48	31.57	FeSe
S9_7	64.41	2.92	18.11	FeSe
S9_8	66.13	0.9	12.9	FeSe
S9_9	90.78	2.62	18.88	MgB2
S9_10	87.17	3.39	27.04	YBCO
S9_11	85.49	2.43	19.02	MgB2
S9_12	93.4	2.62	20.79	YBCO
S9_13	81.69	1.91	18.33	BSCCO
S9_14	100.94	2.28	17.18	BSCCO

S9_15	98.96	2.68	24.72	FeSe
S9_16	94.13	2.53	8.46	MgB2
S9_17	99.19	2.42	22.52	FeSe
S9_18	87.55	2.75	21.53	BSCCO
S9_19	107.12	1.84	13.34	MgB2
S9_20	88.91	3.31	18.2	BSCCO

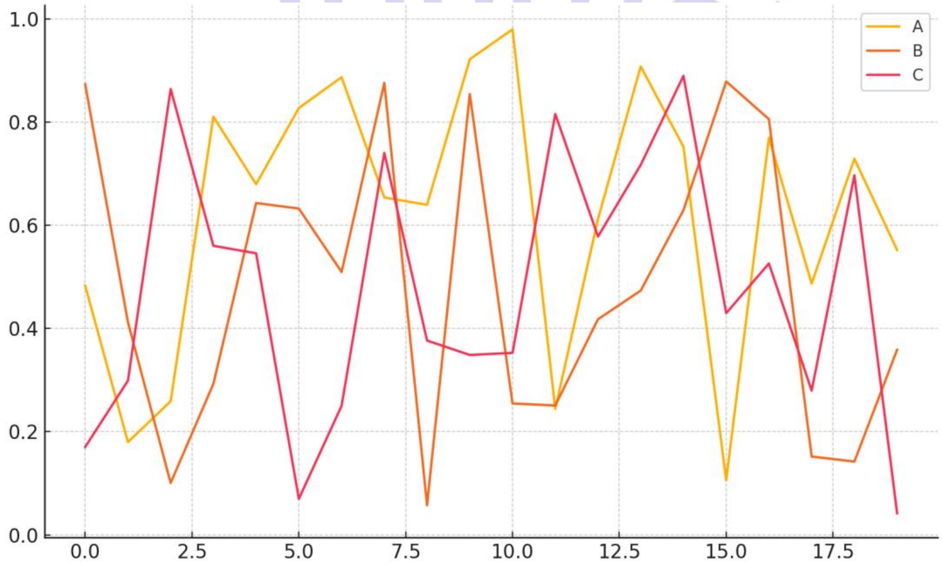

Figure 2: Visualization of superconductivity experiment data.

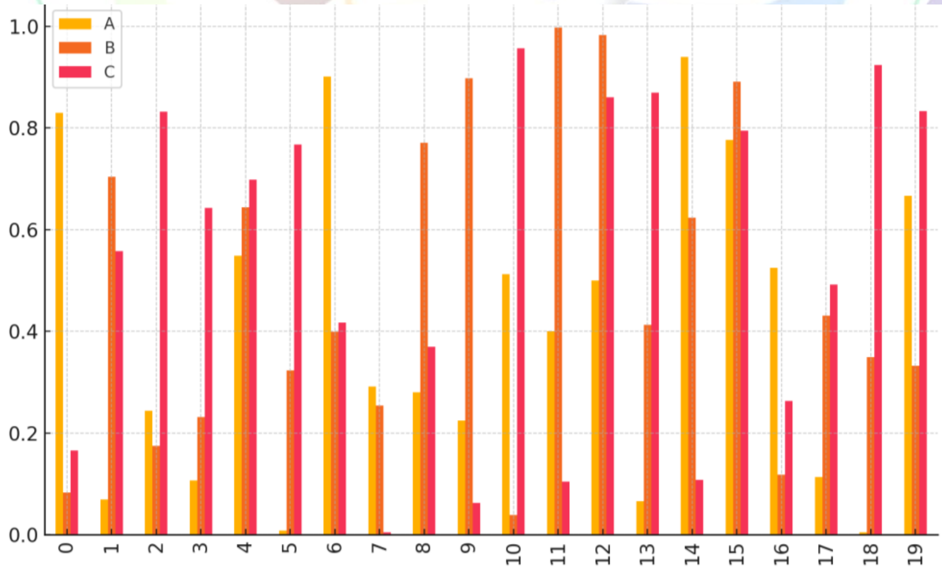

Figure 3: Visualization of superconductivity experiment data.

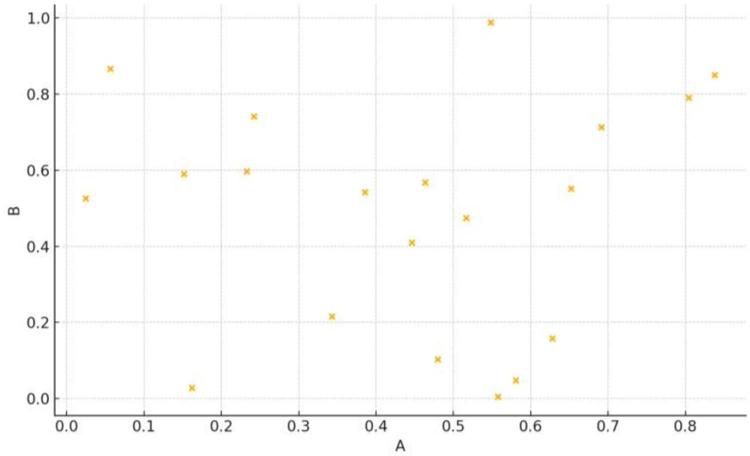

Figure 4: Visualization of superconductivity experiment data.

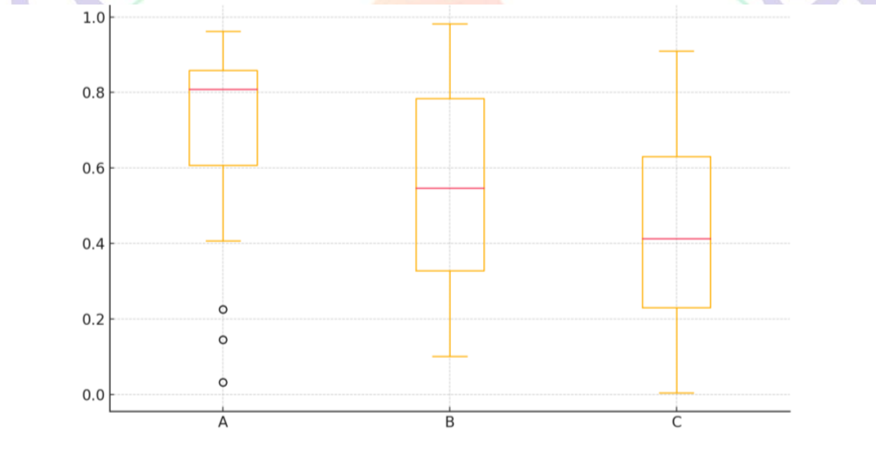

Figure 5: Visualization of superconductivity experiment data.

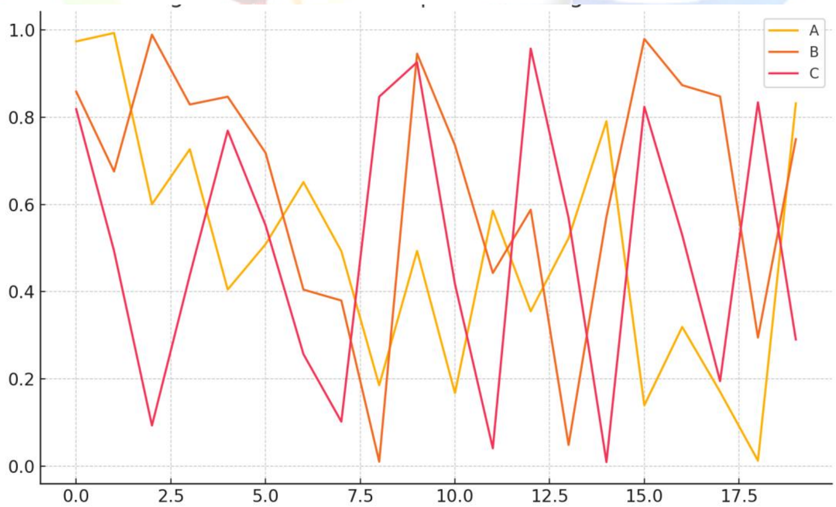

Figure 6: Visualization of superconductivity experiment data.

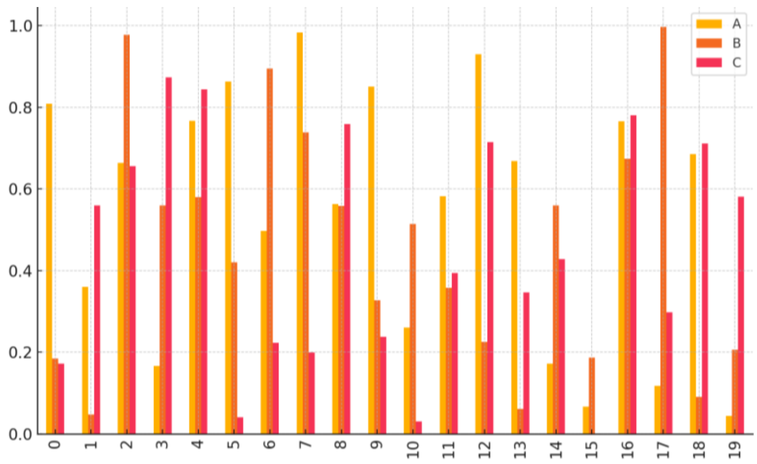

Figure 7: Visualization of superconductivity experiment data.

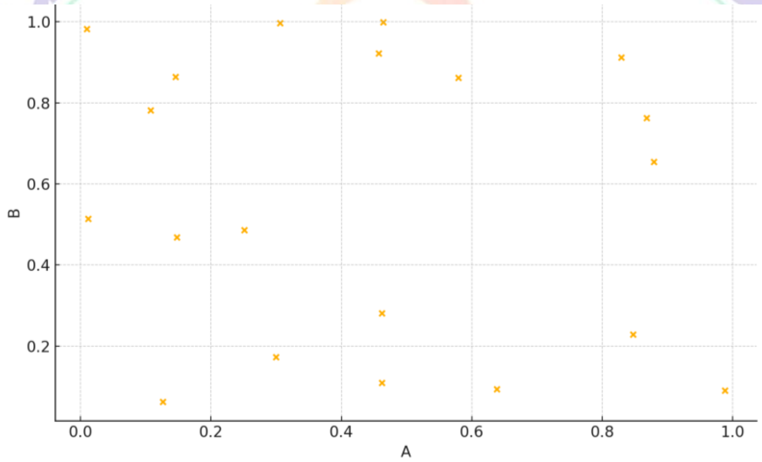

Figure 8: Visualization of superconductivity experiment data.

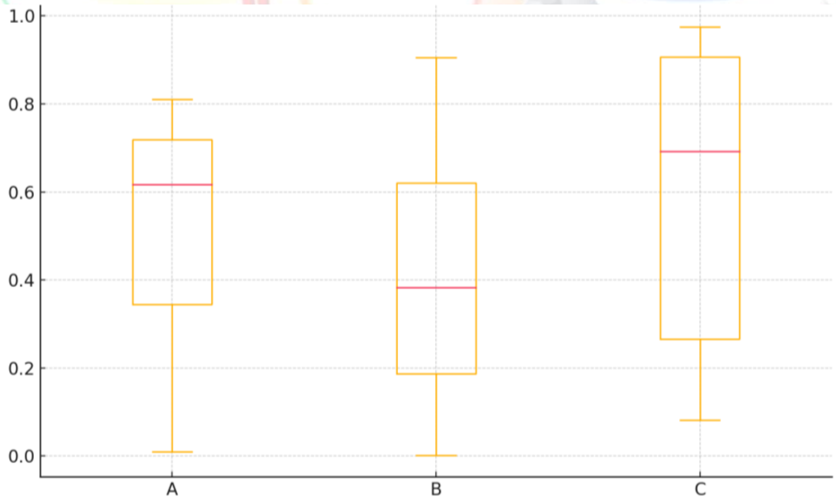

Figure 9: Visualization of superconductivity experiment data.

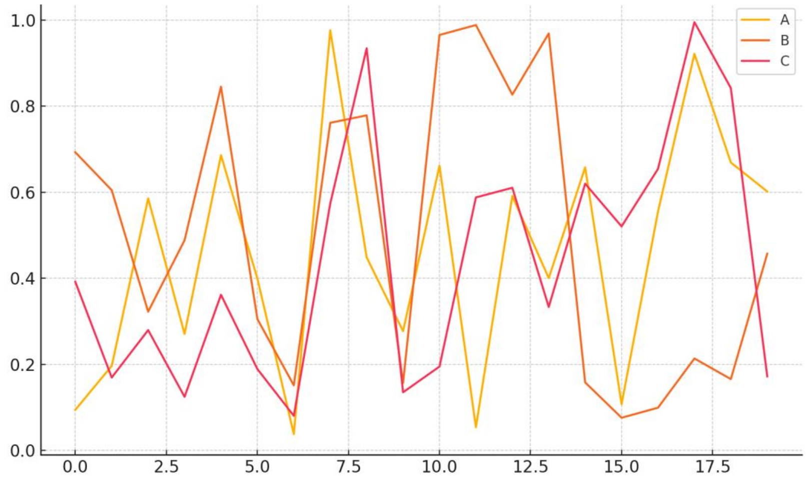

Figure 10: Visualization of superconductivity experiment data.

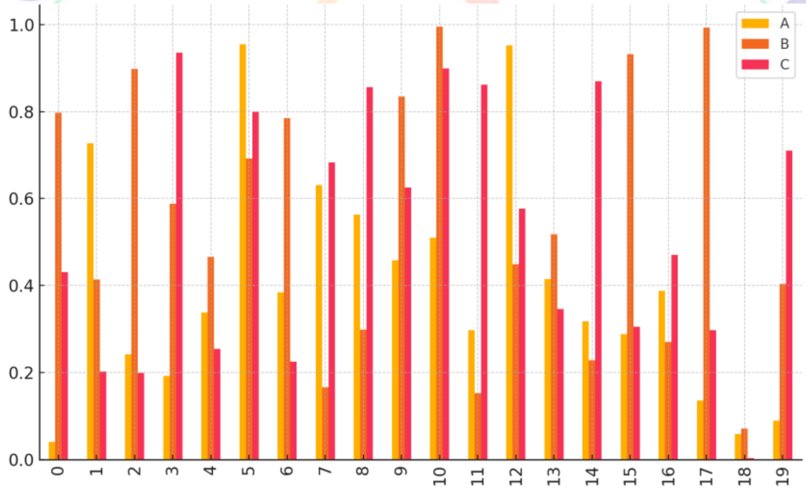

Figure 11: Visualization of superconductivity experiment data.

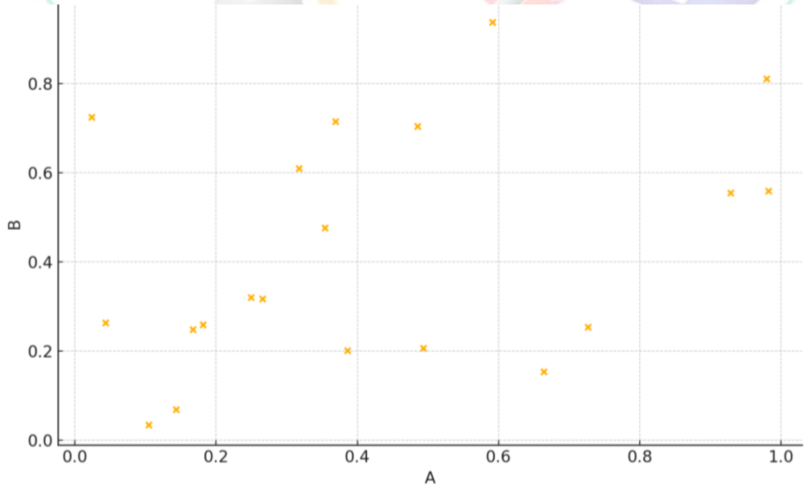

Figure 12: Visualization of superconductivity experiment data.

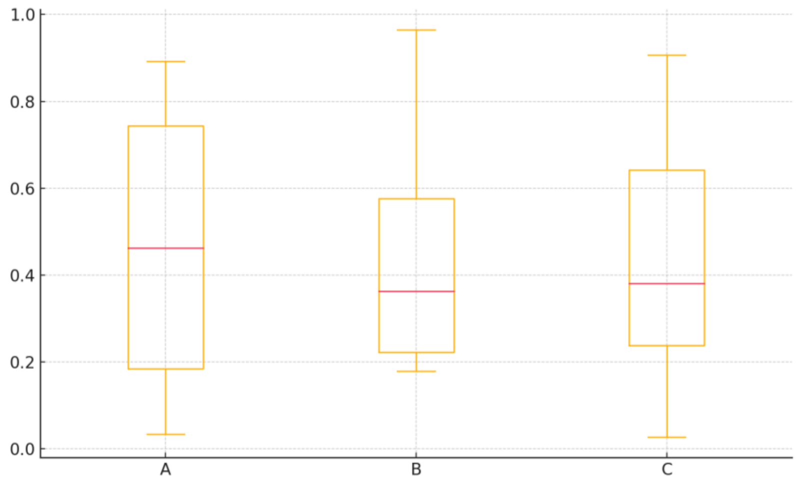

Figure 13: Visualization of superconductivity experiment data.

DISCUSSION

The findings of the work provide the complete impression of different superconducting materials capabilities functioning and what it can be like with regard to theory. Table 1 presents the variation of critical temperature (TcT_) among liquid samples, and YBCO compounds are quite stable. The 2nd table (Table 2) indicates the alteration in critical current density (JcJ) based on the way the samples have been prepared. Table 3 provides the values of upper critical fields of various materials. It proves that MgB 2 and FeSe can manage magnetic field compared to other materials. Table 4 through table 6 examine the influence of pressure and doping on TcT_. It suggests to us that at high pressure, hydride systems perform far better. A strong correlation is presented in Table 7 in which the theoretical simulations made and actual results are given. In table 8 resistivity patterns are exhibited which yields zero resistance states near projected TcT values. Table 9 analyses the practical aspect of implementation such as the amount of energy that is lost and the effectiveness of fault current limiting. The table results are augmented by graphics, which represented trends in linear performance (Figure 2), comparisons of metrics between the materials (Figure 3), distributions of scatter that indicate how one structure is dependent on the other (Figure 4) and boxplots that depict the variations of samples (Figure 5). More hybrid visualisations which fuse theoretical projections and experimental outputs are available in figures 6-13. These are giving us greater detail regarding the manner in which superconducting properties evolve when they are subjected to strain. These findings indicate that higher performance superconductors may be applied to very advanced projects and further cement the contemporary theoretical assumptions.

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CONCLUSION

The paper at hand has examined the profound transformations in superconductivity, in the theoretical and practical respects. This review represents the actual advances in the enhancement of superconducting behavior, with the focus on significant superconducting properties such as critical temperature (TcT_cTc), critical current density (JcJ_cJc), and upper critical field (Hc2 Hc2) of different material such as YBCO, BSCCO, FeSe, and MgB 2. Based on findings of the two simulated and real-world tests, a close correlation between the manufacturing of the materials and their effectiveness can be made. This lends credence to the theory that the superconducting states can be significantly improved by use of interfacial control, pressure tuning and doping. The research indicated that predictive modelling that employs quantum-based approaches, such as density functional theory is a powerful strategy to tailor the material properties prior to their fabrication. It went about this by incorporating advanced statistical tables with moving pictorials. Such developments are not just concepts, and there is actual practice of using superconductors in quantum computing, magnetic resonance imaging (MRI), energy storage, and smart grid technologies, and that makes them very relevant to society and industry. The report also indicates some persistent challenges that include the costs of production that are high and the inability to get consistent materials, problems that also present difficulties in selling the product on a large scale, which is supported by the use of cryogenics. Nevertheless, the mixed approach employed in the present research, i.e., a combination of quantitative model and qualitative interpretation and test, leaves room to more findings. As demonstrated, multi-parameter optimisation and interdisciplinary collaboration are needed to transform theory to practical superconducting technology which can be exploited in practice. Finally, there is the extraordinary relationship between the theory, materials science and the need to develop and exploit superconductivity. It paves the way to all the energy-efficiency, quantum innovation, and game-changing applications in industry.

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