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"IMPACT OF ADVANCED MATERIALS IN ENHANCING THE MECHANICAL PROPERTIES OF PIPING SYSTEMS FOR STRESS ANALYSIS"

Vikas Thakran[1]

[1] *Independent Researcher*

ABSTRACT

An important area of research in engineering, especially for stress analysis, is the effect of modern materials on improving the mechanical characteristics of pipe systems. The research delves into the effects of modern materials on improving the mechanical characteristics of pipe systems, with an emphasis on stress analysis to guarantee structural soundness and operational effectiveness. Various industries within petrochemicals, oil and gas, and power generation rely on pipe systems that need to withstand demanding conditions, intense pressure and elevated temperatures. Through stress analysis industries resolve issues with thermal expansion while managing pressure-induced stresses and seismic forces to ensure safety along with reliable performance. This document groups stress types into three categories: primary, secondary and occasional, while emphasizing the significance of Finite Element Analysis (FEA) and thermal stress analysis methods for complete evaluation. The paper shows how advanced materials advance corrosion protection and enhance material endurance along with meeting regulatory requirements. The analysis evaluates how design efficiency and stress evaluation benefit from two software tools, CAESAR II and AutoPIPE. The research shows that advanced material utilization alongside analytical methods enables sustainable piping systems with cost-effectiveness and resilience to help achieve superior industrial operational standards.

Key Words: *Advanced materials, Stress Analysis, Mechanical properties, Finite Element Analysis (FEA), CAESAR II, AutoPIPE, piping systems.*

I. INTRODUCTION

Pipe is considered essential to the petrochemical sector since it is responsible for the transportation of fluids. Common fluids conveyed in the petrochemical sector include hydrocarbons, water, and steam, all of which may be heated and pressured to varying degrees. Pipes, fittings, valves, gaskets, and flanges are all components of piping systems, which must be well-designed to transfer fluids [1]. The word vein refers to the flexible component of the plant that links various pieces of equipment that are essential to its operation. Equipment often has a sturdy base and is stiff in character. Pipes link two pieces of equipment, and while the equipment is running, its internal temperature and pressure are high [2].

Plant piping systems are exposed to almost every extreme plant condition, including high temperatures, high pressures, high flows, and combinations of these. Along with the previously mentioned corrosion, erosion, hazardous conditions, and radioactivity, pipe design is becoming more complicated, and the process condition is becoming worse as process development advances [3]. There will be strains and movement caused by the equipment's high temperature and pressure. The pipe will expand or shrink according to the temperature differential between installation and operation. The inability of a rigid pipe system to accept expansion leads to strains. Pipes, being the most pliable component of the connections to these machines, must be able to withstand these loads and strains under operational design conditions.

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The use of modern materials greatly improves the mechanical strength of the piping system, making it capable of operating at high temperatures, highly pressurized and in corrosive environments. Stainless steel and Inconel, which are high-strength alloys, are also very tough and resistant to deformation. On the other hand, carbon fiber-reinforced polymer composites are lightweight, strong and possess high fatigue and chemical resistance [4]. A ceramic-lined piping system is resistant to wear and provides thermal insulation, making it ideal in environments subject to abrasion. Besides, modern smart materials such as shape memory alloys and self-healing polymers, which are able to deform under stress and repair the damage suffered, are reliable and do not need much maintenance as well. These improvements in materials are the key contributors to the optimization of piping systems when subjected to stress analysis and in their operation over a long time period as well [5].

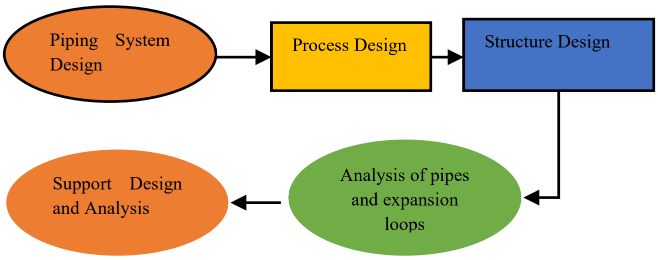
A key component of engineering science is stress analysis, as stresses are the root cause of structural failure in the majority of engineering projects. In order to guarantee that machine components like engines, turbine blades, jumbo jet fuselage, and others can withstand the stresses of their intended use, these components must undergo extensive stress testing [6].

A. Structure of the paper

The structure of this paper is as follows: Section II provides an overview of stress analysis in piping systems; Section III discusses the mechanical properties of materials and their role in stress analysis; Section IV explores the impact of advanced materials on piping systems; Section V presents relevant literature and case studies; and Section VI offers conclusions and suggestions for future research directions.

II. OVERVIEW OF STRESS ANALYSIS IN PIPING SYSTEM

Pipelines utilized in many different industries, such as those dealing with oil and gas, electricity production, chemical processing, and water distribution, rely on stress analysis in piping systems to guarantee their structural stability, safety, and usefulness [7]. The phrase "piping stress analysis" refers to computations that deal with the static and dynamic loads caused by factors including seismic activity, variations in temperature, fluid flow rate, internal and exterior pressures, and gravity [8]. An elongated or expanded hot piping system is possible. A system of cold pipes will shrink. These two things make people anxious. It is necessary to compare the stresses created in pipes with the permissible limits set out by the relevant codes and standards in order to conduct a stress analysis and ascertain the forces acting on the pipes, anchor points, and piping system restrictions. In a specific pipeline system, the size, temperature, and associated equipment determine the sort of analysis that needs to be carried out [9].



Stress Analysis in Piping Systems

In piping systems, the stress analysis is that which depicts the main steps in the process of piping stress analysis. The workflow includes the following stages shown in Figure 1:

- Design of All Components Making the Piping System: This is the uppermost activity that entails the aspect of component making of the piping system.
- Evaluation of Process and Formation of the System: This stage evaluates the requirements of the process and the formation of the system with the requisite piping layout.
- Statically Model for Designs with Load Estimations: This includes estimating and transacting the loads to the piping design with respect to its integrity.
- Stress and Expansion Analysis of Pipes in Loop Systems: This activity includes analyzing that the stress and expansion of the loop pipes in the system do not exceed their operating conditions.

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- Design and Analysis of Support Structures: This activity is the last in which supports for the piping system are designed and analyzed to ensure relief from the stress [7].

A. Advanced Techniques for Stress Analysis in High-Temperature Piping Systems

A combination of advanced techniques with specialized tools determines stress analysis for high-temperature piping systems. Advanced evaluation techniques enable engineers to understand the intricate relationships among temperature, pressure and mechanical loads so the piping system operates safely.

- **Finite Element Analysis (FEA):** The powerful computational tool FEA delivers simulations and stress analyses for piping systems. Engineers build comprehensive piping models to simulate operating conditions consisting of temperature shifts, pressures, and mechanical forces. Through FEA, practitioners identify critical stress areas, helping them enhance design parameters for failure prevention [10].
- **Thermal Stress Analysis:** This specialized approach investigates the heat-related impacts on piping infrastructure. It considers the full thermal stress range, from minimum to maximum operating temperatures, and evaluates temperature gradients' effects on the system. Thermal stress analysis is particularly important for piping systems exposed to extreme temperature variations, as it helps in designing appropriate expansion joints, supports, and other components [11].

B. Types of Stresses in Piping Systems

The stresses in piping systems are categorized based on their origin and nature:

1. **Primary Stress:**
   Primary stress can be caused by both internal and external moments and forces. Because the load that is generating primary stress does not decrease regardless of whether the component in question moves, this type of stress does not self-limit. Pipes experience principal stress in this case due to an expansion junction that lacks restraining hardware. The principal stress here is the result of the fluid pressure times the pipe's area. When the system is under pressure, it happens constantly. The untied bellows will continue to press on regardless of the displacement of the pipe since primary stresses are not reduced by the piping's movement or yielding, and the tolerances for primary stresses are smaller than those for other stresses.

2. **Secondary Stress:**
   When a pipe experiences changes in temperature, it expands and contracts. To accommodate the growth, the pipe system must be sufficiently flexible. The pipe is exerting tension because it is pressing against a defined constraint. Because of their inherent ability to limit themselves, thermal stresses are considered "secondary stresses." Deformation or yielding of the component lowers stress. This self-limiting behavior allows for higher pressures than in the primary example. While stresses over the yield point may initially be tolerable, the cumulative effect of repeated heat cycles at high stresses can eventually overwhelm the material's fatigue capacity, resulting in failure [12].

3. **Occasional Stresses:**
   There are infrequent wind and earthquake loads. Stress, in this case, is caused by seismic loads acting in a sideways direction. Since seismically induced loads are not common, the produced stresses can be greater than the fundamental loads. According to ASME pipe regulations, seismic stresses can normally be 20% more than primary stresses. It should be possible for the equipment to withstand these infrequent shocks without suffering any harm [8].

C. Pipe Stress Analysis Software

Software for pipe stress analysis is essential to the planning and assessment of piping systems. by automating complex stress calculations and offering comprehensive insights into the system's mechanical behavior. These tools enable engineers to ensure safety, reliability, and compliance with applicable standards. Below is an explanation of some widely used pipe stress analysis software tools:

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1. CAESAR II

Pipe systems subjected to static and dynamic stresses, including weight, pressure, heat, earthquake, and more, require quick and accurate analysis, CAESAR II is an all-inclusive software application for pipe stress analysis. It is capable of analyzing complicated and large-scale pipe networks [13]. CAESAR II stands out from the competition because it has analytical features and calculating methodologies that no other application offers. Whatever your system design or troubleshooting needs may be, CAESAR II will provide findings that fully characterize the system's behavior according to rules and design constraints derived from recognized industry standards. More is done faster and with less room for mistakes with CAESAR II. Regardless of the load situation, you may build output reports that display any data [14].

The system's operational, sustained, and growth scenarios were all included in the stress study. This is a quick rundown of the steps involved in doing a CAESAR stress analysis.

- Creating a model of the pump-to-vessel nozzle pipeline, including all necessary support structures.
- The pressure vessel may be modeled and analyzed to determine the displacement that occurs as a consequence of expansion in the nozzle.
- The piping system receives these displacements at the point where the pipe meets the nozzle at the pressure vessel [2].
- The model is run through three different scenarios: the expanding case, the operational case, and the sustained case. This guarantees that the load on the vessel nozzle, strains, and displacements are all within the specified ranges and within the vendor's specifications [15].
- In the event of a system failure, it is adjusted by rerouting pipes, moving supports, adding loops, etc., so stresses and loads remain within acceptable ranges [6].

2. AutoPIPE

A worldwide general pipeline stress analysis program, AutoPIPE is released by the Bently Software Company of the US. It is more logical and correct to use AutoPIPE software. Many different sectors make use of it, including those dealing with oil and gas, electricity production, water treatment, chemical processing, and underground pipeline and flange stress analysis. The program provides a solid foundation for assessing the stability of pipe networks and guarantees conformity with international norms. AutoPIPE supports advanced modeling capabilities, including the simulation of pipe supports, fittings, nozzles, and buried or subsea pipelines [16].

D. Benefit of Piping Systems for Stress Analysis

The following are the Benefits of Piping Systems for Stress Analysis:

- Software for pipe stress analysis does more than only give the pipe designer information about displacements, stresses, and support loads; it also does other helpful things.
- A separate table lists the displacements for expansion joints or bellows, making assessment easier [17]. There is perpetual worry with GRP systems about going above the displacement limits of the bellows.
- A comprehensive output includes an XYZ coordinate map of the system showing the positions of every node. When presented in tabular form, this data is often very helpful.
- The general contractor and pipe fabricator both take support types and loads into account when estimating costs. The loads associated with each pipe support are included in the output file, which are determined throughout the pipe design process.
- Using software for pipe stress analysis has additional benefits, one of which is a bill of materials [18]. The software will calculate the totals by scanning the entire system and calculating the various pipe diameters, fittings, valves, bellows, etc. There is also a breakdown of the total weight for each pipe diameter and fitting available. This data is sometimes offered in a lovely tabular style and is a "bonus" feature of pipe analysis software; nonetheless, it is tedious to compile by hand. All parties involved in the bidding process for work could benefit from this data.

III. MECHANICAL PROPERTIES AND THEIR ROLES IN STRESS ANALYSIS

A material's mechanical qualities are those that influence its strength and its malleability. The aerospace and

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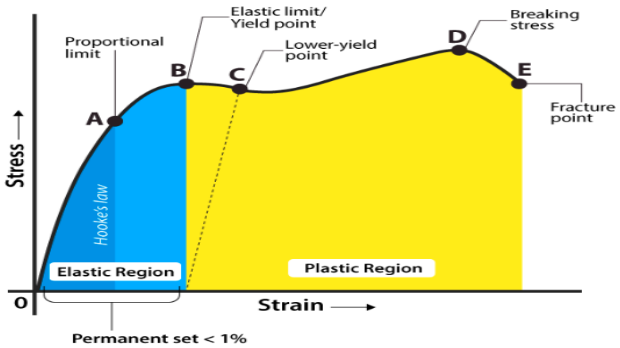
automotive sectors make extensive use of some common mechanical characteristics [19]. An indicator of these properties is a material's mechanical stress and load bending strength, which is associated with how the material acts when subjected to stress [20]. The engineer may use the results of a mechanical property determination as design data or as a quality control measure for the materials themselves. Stress analysis is a fundamental aspect of mechanical engineering and materials science, critical for designing and evaluating structures and components. The effectiveness of stress analysis depends heavily on understanding the mechanical properties of materials, as these properties determine how materials respond under various loads and environmental conditions [21].

Strength and Stress-Strain Curve

A material's strength is its resistance to breaking or yielding under the influence of applied pressures from outside. Material ultimate strength (D) is the maximum load it can bear before snapping. Figure 2 illustrates the link between stress and strain. The tensile test determines the material's ductility and yield strength through the analysis of its stress and strain curve. The capacity to return to its original size (elasticity) is maintained once a material reaches its elastic limit, as shown in Figure 2, and plasticity kicks in subsequently. To begin experiencing the effects of necking on the specimen, the material must be stressed beyond its ultimate stress point (D). In the range of ultimate tensile strength to yield points, strain hardening is maintained. Hooks law is faithfully obeyed by a material up to a proportionate limit.



Stress-strain relationship curve

The stress-strain curve is used to compare the stress and strain values up to the elastic limit in order to calculate the Young's modulus of materials. The A-B range is shown in the illustration as the elastic limit. A material's strength is defined as its capacity to withstand loads without deterioration or failure. Its capacity to respond uniformly to tensile, compression, and shear forces without breaking is also known as its resistance to rupture. The strength of a substance is its ultimate resistance to deformation, put simply. The ability of a material to resist rupturing under tensile stress is another name for its resilience.

Elasticity:

The removal of external stresses causes materials that have been deformed to revert back to their original shape. One example is the expansion or compression of a spring. Materials for machinery and tools should have this quality. Rubber is less elastic than steel. A material's elastic attribute is its tensile strength. The limits of proportionality and elasticity show that there is elasticity. Deformation that does not last forever is another name for it. This elastic zone has two sub-properties. The limits in question are the proportional and elastic kinds [22].

Durability:

A material's yield strength is its capacity to retract into a thin wire when subjected to tensile stress. Ductile materials are very plastic and robust. A few examples of ductile materials include mild steel, tin, nickel, copper, aluminum, and gold. Common measures of ductility include percentage elongation and percentage decrease in area. Stress analysis incorporates durability to account for long-term loading conditions and repeated cycles of stress. The term "durability" describes a material's resistance to the gradual deterioration that comes with use and exposure to the elements. Durable materials ensure long-term functionality of the piping system [22].

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Plasticity

A material achieves plastic deformation when shear stress on slip planes crosses its critical value, leading to slipping beyond the elastic range. The slipping-induced displacement is irreversible; the crystal planes retain their new orientations even when the pressures are removed. A material is tough if it can sustain continuous strain without cracking or breaking. The ability of a material to undergo persistent deformation when subjected to a load is being referred to here.

IV. IMPACT OF ADVANCED MATERIALS ON PIPING SYSTEMS

The development and adoption of advanced materials have significantly transformed the design, construction, and performance of piping systems across industries. These materials address the limitations of traditional materials like carbon steel and low-alloy steel, offering enhanced properties to meet the demands of modern applications.

A. Environmental Impact

There are two types of environment impacts of advanced materials on piping systems:

- **Sustainability:** Some materials have a lower environmental impact than others. The entire life cycle of product production, from extraction through processing and disposal, needs assessment.
- **Regulations:** To comply with environmental regulations, the industry must adhere to specific rules which limit certain materials.

B. Aesthetics and Appearance

When visible piping systems exist in residential or commercial settings aesthetic quality should become a factor. Visibility-driven facilities commonly use copper or stainless-steel materials because of their attractive visual appearance.

C. Durability and Longevity

- **Corrosion Resistance:** Choosing corrosion-resistant material as the manufacturing base helps lengthen equipment lifetime and reduces recurring maintenance costs
- **Wear and Tear:** The material must be durable sufficiently to withstand the mechanical stresses & wear and tear related to the application.

D. Functionality and Performance

- **Pressure and Temperature:** The application requires materials that possess sufficient strength to resist both pressure changes and operational temperature fluctuations.
- **Flow Rate:** Efficient fluid or gas transport depends on material flow characteristics.
- **Chemical Compatibility:** Corrosion and contamination need to be avoided through selection of materials that show resistance to transported chemicals.

E. Safety

- **Leak Prevention:** Material selection plays an essential role in leak prevention because hazardous substances need protection from unsafe leakages that endanger workers.
- **Compliance with Regulations:** To guarantee safety and accident prevention, all industry standards and regulations must be met by piping materials.

F. Cost-Effectiveness

- **Initial Cost:** Initial expenses of selecting the materials should be evaluated as one factor. The evaluation of long-term expenditures, particularly maintenance requirements repairs alongside potential replacement needs, should take precedence.
- **Life Cycle Cost:** Companies need to use the complete ownership costs, including initial purchase amounts and future expenses when making their decisions.

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V. Literature review

This section provides a survey of the literature on the role of advanced materials in enhancing the mechanical properties of piping systems for stress analysis.

Gong, Zhu and Deng (2021) as the first pipe is jacked, the surface settlement value gradually rises and tends to remain stable; however, when the second pipe is jacked, the first pipe's final settlement value slightly drops and the centre of the surface settlement trough moves from the first pipe to the second pipe. Because the second pipe's settlement value is somewhat lower than the first pipe's, the parallel pipe's jacking sequence should be carefully chosen during construction. The earth pressure reading above the pipe jacking rises first and then falls as the pipe is jacked [23].

Qi, Li and Li (2020) the pressure piping system, dynamic stress in hydraulic pipes is a major contributor to fatigue damage. Since damage to the hydraulic system eventually manifests itself in stress levels, it is vital to measure the dynamic stress under real-world operating conditions through testing and fatigue life evaluation. A certain model's hydraulic pipeline system undergoes an online dynamic stress test, which yields measurable data. The test then analyses the fatigue hazard method using the rain flow counting technique, and lastly, the pipeline system's fatigue life analysis [24].

Xu and Wang (2020) the accurate stiffness of the supports structure in dynamic model was carried out using Sacs software. Secondly BOSPulse from Dynaflow has been used to evaluate the pressure pulsations out of the pumps, and then the unbalanced harmonic pulsation forces were implemented into Caesar II analysis to get the stress analysis and fatigue assessment. Finally the inducement of vibration and main vibration source were explored [25].

Ma et al. (2018) looked at three different types of stress design criteria. The planned pipe system was subjected to stress and deformation analyses using the AutoPIPE program. The system's strength was evaluated in accordance with the applicable ASME standards. Findings reveal that pressure differential between the pipeline's interior and exterior had the most impact on circumferential stress, while pipeline node constraint shape and temperature differential between the pipeline's interior and exterior had the greatest impact on longitudinal stress [26].

Prabhu Kishore and Prabhu (2018) detail the three steps of the stress analysis process: Pump modeling, analysis load case preparation, and output result analysis. Nozzles on spinning equipment should not be subjected to external loads more than the authorized loads. In addition to detailing the procedure used for stress analysis of a pump pipe system, it shows how misalignment may impact mechanical function and lead to annoying vibrations when excessive loads are applied. In this stress system, two pumps' standard discharge and suction lines participate. For pumps used in routine refinery service, the API 610 standard provides equations for calculating permitted forces and moments [27].

A summary of the reviewed studies is provided in Table I for a concise overview, highlighting key findings, methodologies, challenges, and limitations in the field of piping system design and stress analysis.

Reference	Study	Key Findings	Challenges	Limitations
Gong, Zhu and Deng (2021)	Surface settlement during parallel pipe jacking	1. Surface settlement increases with the first pipe and shifts toward the second during its jacking. 2. Earth pressure above jacked pipe increases then decreases.	Managing settlement and earth pressure fluctuations during multi-pipe jacking.	Limited to specific pipe jacking configurations; may not generalize to all soil or pipe types.
Qi, Li and Li (2020)	Analysis of the hydraulic pipeline system's fatigue life	1. Dynamic stress is a major cause of fatigue. 2. Analysis of fatigue hazards using the rain flow counting technique.	Real-time stress measurement under actual operational conditions.	Focused on one model; results may not be generalizable across all hydraulic systems.
Xu and Wang (2020)	Vibration and fatigue in support structures	1. Used SACS, BOSPulse, and Caesar II for dynamic modeling and fatigue analysis. 2. Identified main vibration sources.	Integrating multiple simulation tools and accurately modeling harmonic forces.	Model accuracy depends on correct input parameters; may not cover all real-world complexities.
Ma et al. (2018)	Stress and deformation analysis using AutoPIPE	1. Circumferential stress mainly affected by pressure differential. 2. Longitudinal stress affected by node constraint and temperature differential.	Evaluating complex stress responses under multiple design criteria.	Application-specific; stresses analyzed under a controlled design model only.
Prabhu Kishore and Prabhu (2018)	Analysis of stress in pumppipe systems	1. Misalignment can lead to vibrations and mechanical failures. 2. Follows API 610 standard for force/moment allowances.	Ensuring correct alignment and allowable loads during pump operation.	Focused on refinery applications; might not be applicable to non-standard pump systems.

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VI. CONCLUSION & FUTURE WORK

The use of advanced materials in piping systems has proven to significantly enhance their mechanical properties, offering improved performance in terms of strength, durability, and resistance to environmental factors. Materials such as high-strength alloys, composites, and polymers have been shown to increase the overall reliability of piping systems, especially under high-stress conditions. This paper provided an overview of the different types of stresses in piping systems, including primary, secondary, and occasional stresses, as well as the methodologies used for performing stress analysis. The significance of Finite Element Analysis (FEA) combined with Thermal Stress Analysis becomes clear for stress distribution assessment and piping system design optimization to minimize failures. The integrated usage of CAESAR II and AutoPIPE tools has improved stress evaluation procedures by allowing accurate modeling under various operational circumstances. Advanced materials adoption brings improved longevity, enhanced resistance to corrosion, and better compliance with industry standards, which results in decreased maintenance expenses and prolonged system lifespan.

Next-generation materials verifying superior thermal and mechanical properties deserve exploration, while the use of AI and ML requires adoption for stress analysis optimization. Predictive algorithm development allows real-time pipeline monitoring with proactive maintenance systems that decrease operational downtime and reduce equipment failures

REFERENCES

1. T. Pipit Muliyah, Dyah Aminatun, Sukma Septian Nasution, Tommy Hastomo, Setiana Sri Wahyuni Sitepu, PIPING HANDBOOK, vol. 7, no. 2. 2020.
2. R. N. Rao, M. Maiya, S. Prabhu, G. Santhosh, and G. Hebbar, “The analysis of a piping system for improvement of a system in a process unit,” in Materials Today: Proceedings, 2021. doi: 10.1016/j.matpr.2021.02.595.
3. J. Tan and M. V. Karwe, “Inactivation and removal of Enterobacter aerogenes biofilm in a model piping system using plasma-activated water (PAW),” Innov. Food Sci. Emerg. Technol., 2021, doi: 10.1016/j.ifset.2021.102664.
4. Y. H. Rajarshi Tarafdar, “Finding Majority for Integer Elements,” J. Comput. Sci. Coll., vol. 33, no. 5, pp. 187–191, 2018.
5. M. Prachi, N. Tambe, K. K. Dhande, and N. I. Jamadar, “Flexibility and Stress Analysis of Piping System using CAESAR II-Case Study,” IJERT, 2014.
6. M. K. Boadu, E. O. Abankwa, and L. A. Anaba, “A Concise Review on Applications and Challenges of Stress Analysis,” Int. J. Sci. Tech. Res. Eng., vol. 4, no. 6, pp. 1–5, 2019.
7. Y. B. Shinger, “Stress Analysis of Steam Piping System,” J. Appl. Mech. Eng., 2015, doi: 10.4172/2168-9873.1000158.
8. S. Hwang, M.-S. Kim, and J.-H. Lee, “Thermal Stress Analysis of Process Piping System Installed on LNG Vessel Subject to Hull Design Loads,” J. Mar. Sci. Eng., vol. 8, p. 926, 2020, doi: 10.3390/jmse8110926.
9. “DESIGN AND STRESS ANALYSIS OF FLARE PIPING,” no. 4, pp. 5–12, 2017, doi: 10.21276/ijcesr.2017.4.4.2.
10. V. Jagota, A. P. S. Sethi, and K. Kumar, “Finite element method: An overview,” Walailak Journal of Science and Technology. 2013.
11. B. Sontakke, G. Gandhe, S. Dhondge, and Head, “Study of Thermal Stress Analysis,” J. Maharaja Sayajirao Univ. Baroda, vol. 55, no. 1, 2021.
12. V. Thakran, “Environmental Sustainability in Piping Systems : Exploring the Impact of Material Selection and Design Optimisation,” Int. J. Curr. Eng. Technol., vol. 11, no. 5, pp. 523–528, 2021.
13. R. B. and P. V. K. Reegan C, R Tarmizh Selvan, T T M Kannan, “Product Analysis and Stress Analysis of,” Int. J. Mech. Eng. Robot. Res., vol. 4, no. 2, pp. 154–161, 2015.
14. S. Bisht and F. Jahan, “An Overview on Pipe Design Using Caesar II,” Int. J. Emerg. Technol., vol. 5, no. 2, pp. 114–118, 2014.
15. S. Pahune, “Sensor Data Collection and Performance Evaluation using A TK1 Board,” University of

 ISSN : 2455-9679

Memphis, 2019. [Online]. Available: https://digitalcommons.memphis.edu/etd/2372
16. L. Ni, Q. Zhen, and B. Li, “Research on Failure of Tee Pipe Based on AutoPIPE,” in Journal of Physics: Conference Series, 2019. doi: 10.1088/1742-6596/1325/1/012038.
17. A. Goyal, “Enhancing Engineering Project Efficiency through Cross-Functional Collaboration and IoT Integration,” Int. J. Res. Anal. Rev., vol. 8, no. 4, pp. 396–402, 2021.
18. A. and P. Khare, “Cloud Security Challenges : Implementing Best Practices for Secure SaaS Application Development,” Int. J. Curr. Eng. Technol., vol. 11, no. 6, pp. 669–676, 2021, doi: https://doi.org/10.14741/ijcet/v.11.6.11.
19. J. Q. Gandhi Krishna, “Implementation Problems Facing Network Function Virtualization and Solutions,” IARIA, pp. 70–76, 2018.
20. V. Kolluri, “Revolutionary Research on the AI Sentry: An Approach to Overcome Social Engineering Attacks Using Machine Intelligence,” Int. J. Creat. Res. Thoughts, vol. 7, no. 3, pp. 590–593, 2019.
21. “Development of Hybrid Composite for Automobile Application and its Structural Stability Analysis Using ANSYS,” Int. J. Mod. Stud. Mech. Eng., 2017, doi: 10.20431/2454-9711.0301004.
22. S. M. Subramanian, “Mechanical Properties of Materials: Definition, Testing and Application,” Int. J. Mod. Stud. Mech. Eng., vol. 6, pp. 28–38, 2020, doi: 10.20431/2454-9711.0602003.
23. J. Gong, X. Zhu, and Q. Deng, “Experimental analysis on construction mechanical properties of parallel rectangular pipe jacking based on similar model test,” in 2021 7th International Conference on Hydraulic and Civil Engineering and Smart Water Conservancy and Intelligent Disaster Reduction Forum, ICHCE and SWIDR 2021, 2021. doi: 10.1109/ICHCESWIDR54323.2021.9656254.
24. X. Qi, J. Li, and Y. Li, “Dynamic Stress Testing And Fatigue Life Analysis Of Hydraulic Piping System For Civil Aircraft,” in IET Conference Proceedings, 2020. doi: 10.1049/icp.2021.0477.
25. H. M. Xu and B. Wang, “Vibration analysis of high pressure mud piping systems and vibration reduction method,” in Proceedings - 2020 3rd World Conference on Mechanical Engineering and Intelligent Manufacturing, WCMEIM 2020, 2020. doi: 10.1109/WCMEIM52463.2020.00157.
26. Q. Ma, W. Liang, Y. Zhu, and C. Zhao, “Design and Analysis of Subsea Manifold Piping Systems,” in Proceedings - 2018 5th International Conference on Information Science and Control Engineering, ICISCE 2018, 2018. doi: 10.1109/ICISCE.2018.00148.
27. N. Prabhu Kishore and S. Prabhu, “Modeling and Stress Analysis of Pump Piping,” in IOP Conference Series: Materials Science and Engineering, 2018. doi: 10.1088/1757-899X/455/1/012100.