Fabrication and Thermomechanical Performance Evaluation of an 80-Tonne Uniaxial Hydraulic Hot Press

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Abstract*: This paper presents the design, fabrication, testing, and performance evaluation of an 80-tonne uniaxial hydraulic hot press, constructed from locally sourced materials with the objective of delivering a cost-effective, multi-functional workshop machine. Conventional hydraulic presses operate under cold working conditions; however, the novelty of this study lies in the simultaneous integration of high compressive pressure and elevated temperature enabling hot pressing operations such as powder sintering, metallurgical compaction, and thermomechanical forming. The machine frame was fabricated from A36 hot-rolled carbon steel C-channels, and all primary structural components were designed to meet established engineering safety and reliability standards. Design calculations were performed using established empirical relationships. Following fabrication, the assembled press was subjected to progressive load testing and thermal performance validation using high-density polyethylene (HDPE) powder. The press demonstrated satisfactory structural rigidity, hydraulic integrity, and thermal functionality throughout all performance evaluations. The total fabrication cost was significantly lower than the equivalent imported machine, demonstrating the economic and technological viability of locally engineered workshop equipment in alignment with United Nations Sustainable Development Goals 1 and 9. This equipment will find wide application in simultaneous high-pressure and high-temperature (hot working) operating conditions.

***Keywords*: Hydraulic press; hot press; fabrication; Pascal's law; sintering; mild steel; uniaxial compaction.**

1. Introduction

Hydraulics, as defined by Kaushik (2016), is the branch of science concerned with the transmission of energy and the behavioral dynamics of liquids in motion. The term “press” denotes the application of force upon an object or surface, compelling movement or compression against resistance. A hydraulic press, as described by Mahale et al. (2017), Ameya et al. (2018), Puthra et al. (2023), Kumar and Prashanth (2017), Kaushik (2016), Sengar et al. (2020), Kamate and Bagi (2016), David et al. (2019), and Rani et al. (2021), is a device that uses pressurised fluid within a hydraulic cylinder to generate a controlled compressive force. Grounded in Pascal’s law, which states that pressure applied to a confined and incompressible fluid is transmitted equally in all directions; this principle enables the magnification of relatively small input forces into substantial compressive loads. Since its invention by Joseph Bramah in 1795, then known as the Bramah Press, the hydraulic press has undergone continuous development, expanding in capacity, precision, and operational scope (Adesina et al., 2018; Okolie et al., 2020; Kumar and Prashanth, 2017; Sengar et al., 2020). Contemporary presses are classified into three principal categories: hydraulic presses, which rely on hydrostatic fluid pressure; screw presses, which employ power screws for force transmission; and mechanical presses, which utilize kinematic linkages (Sumaila et al., 2011; Adesina et al., 2018; Anjum et al., 2020; Ojo et al., 2020). The hydraulic press maintains its position as one of the most indispensable machines in modern manufacturing, materials engineering, and workshop practice. It finds wide application in industrial operations such as forging, stamping, blanking, drawing, and powder compaction (Kaushik, 2016; Sengar et al., 2020). Despite widespread global adoption, the majority of hydraulic presses deployed in Nigerian and sub-Saharan African workshops are imported products, incurring substantial procurement costs that are ultimately transferred to end-users and curtail local manufacturing competitiveness. This research addresses the dual challenge of import dependence and the need for indigenous technological capacity by designing and fabricating an 80-tonne hydraulic hot press using locally available raw materials and standard manufacturing processes. What distinguishes this machine from conventional hydraulic presses is the integration of a thermal system comprising an electric heating mantle enabling simultaneous high-pressure and high-temperature operation. This hot working capability expands the machine's utility to include powder sintering, thermoplastic compaction, and elevated-temperature metallurgical processes that cold-working presses cannot perform. As such, this machine addresses the core imperatives of engineering design, encompassing functionality, high performance, operational reliability, and cost-effectiveness (Rani et al., 2021).

2. Materials and Methods

A. Machine Architecture and Component Overview

The hydraulic hot press is built around four primary subsystems: (i) the H-type structural frame, (ii) the hydraulic actuation system, (iii) the working platen assembly, and (iv) the thermal delivery system. Each subsystem was independently designed, fabricated, and validated before final assembly.

B. Materials Selection

Material selection was governed by a multi-criteria framework that considered mechanical strength, machinability, weldability, cost, and local availability consistent with the design philosophy outlined by Okolie et al. (2020) and Kumar and Prashanth (2017). The following components and their corresponding materials were employed:

1) H-Type Structural Frame

The primary load-bearing frame was fabricated from A36 hot-rolled carbon steel C-channels, each measuring 750 × 250 × 7 mm in cross-section, sourced from standard 20-foot beam stock. A36 steel was selected for its well-documented mechanical properties: a density of 7.8 g/cm³, Young's modulus of 200 GPa, Poisson's ratio of 0.26, yield strength of 250 MPa, and ultimate tensile strength of 420 MPa. Its chemical composition predominantly iron (98%) with manganese (1.03%), silicon (0.40%), carbon (0.26%), and trace elements classifies it as a manganese-silicon low-alloy steel, conferring both structural integrity and ease of fabrication.

The completed H-frame had outer dimensions of 725 mm (height) × 380 mm (width), supported on a base plate of equivalent footprint. The C-channel section employed throughout frame construction had web and flange dimensions of 75 × 40 mm. This geometry provides the necessary second moment of area to resist the bending moments generated during full-load press operations while maintaining a manageable overall machine weight.

2) Platens (Ram Plates)

Upper and lower platens were fabricated from high-carbon steel plate. The lower platen serves as the primary working stage and is adjustable along the H-frame columns via a series of bolted connections through 15 mm holes spaced at 10 cm intervals enabling the operator to accommodate workpieces of varying dimensions without frame modification.

3) Fasteners

Hexagonal high-carbon steel bolts, nuts, and washers were used throughout the assembly. These fasteners exhibit high wear resistance and were sized using the Khurmi and Gupta (2005) design equations for bolt core diameter, initial tension, and stress area ensuring that fastener failure modes were comprehensively accounted for in the structural design.

4) Hydraulic Jack

An 80-tonne capacity commercially procured hydraulic jack was integrated as the primary actuating element. The jack comprises a slave cylinder (smaller diameter, housing the hydraulic fluid) and a master cylinder (larger diameter), connected by hydraulic tubing. Application of force to the slave piston compresses the hydraulic fluid, which transmits through to the master cylinder producing a magnified output force proportional to the ratio of the cylinder cross-sectional areas. A calibrated pressure gauge was fitted directly to the jack to provide real-time pressure monitoring during all operations.

5) Return Springs

Two helical compression springs fabricated from tempered carbon steel were installed between the upper and lower platens. These springs serve dual functions: restoring the lower platen to its neutral position after each press cycle, and stabilising the platen assembly during hydraulic loading to prevent lateral misalignment. Each spring was selected to provide a spring constant commensurate with the weight of the lower platen and anticipated operational loads.

6) Heating System

The thermal subsystem consists of a heat source using an electric resistance heating mantle capable of achieving the temperatures required for powder sintering and thermoplastic compaction (120–150 °C for HDPE trials; higher for metallic sintering operations). Temperature monitoring was achieved using a Type K thermocouple (comprising two dissimilar conductive wires, total length 1 m) connected to a digital display unit.

7) Mold

A detachable cup-and-lid mold assembly was fabricated from mild steel via sand casting of brass scrap. The mold houses powdered workpieces during sintering and compaction operations, and its detachable design permits rapid die changes without disassembly of the main press frame. The summary of the components is presented in Table 1:

Table 1
Components of the hydraulic hot press and materials employed

S/N	Component	Material	Key Properties
1	H-Type Frame	A36 Hot-rolled C-channel steel	UTS 420 MPa, E = 200 GPa
2	Platens (Upper & Lower)	High-carbon steel plate	High hardness, wear resistance
3	Bolts, Nuts & Washers	High-carbon steel	High tensile strength, corrosion resistance
4	Hydraulic Jack	Commercial (procured)	80-tonne rated capacity
5	Return Springs	Tempered carbon steel	High spring constant, elasticity
6	Electric Heating Mantle	Resistance heating element	Controllable temperature output
7	Pressure Gauge	Commercial (procured)	Real-time pressure monitoring
8	Thermocouple (Type K)	Dissimilar conductor wires	Temperature range: 0–1200 °C
9	Mold Assembly	Mild steel (sand-cast)	Cup & lid design, detachable

C. Design Calculations

Structural and hydraulic design calculations were performed prior to fabrication to ensure that all components could sustain the rated 80-tonne (approximately 785 kN) operational load with adequate safety margins. The principal design relationships employed are summarised below.

1) Bolt Sizing

The core diameter of each fastening bolt was determined using the Khurmi and Gupta (2005) relationship for external tensile loading:

$$D_c = \sqrt{\left[\frac{4P}{(n\pi\sigma_t)}\right]}$$

where Dc is the core diameter, P is the external load on the cover plate, n is the number of bolts and σ_t is the allowable tensile stress of the bolt material. Initial bolt tension and stress area were additionally calculated using the Sumaila and Ibhadode (2011) relationships to ensure pre-loading adequacy under service conditions.

D. Fabrication Protocol

The fabrication of the hydraulic hot press followed a structured, sequential manufacturing protocol:

Design calculations and material selection: All components were dimensioned and materials specified prior to procurement.

Frame construction: C-channel steel was measured and scribed using a precision steel rule and metal scriber. Sections were cut using a precision cutting machine, with appropriate dimensional tolerances observed throughout. Columns were tack-welded to the base plates using shielded metal arc (electric arc) welding, followed by full penetration welds after dimensional verification.

Platen preparation and drilling: hole positions for the adjustable lower platen were marked at 10 cm intervals along both frame columns, and 15 mm diameter holes were drilled using a pillar drill to maintain positional accuracy.

Mold fabrication: the cup-and-lid mold was cast from brass scrap using the sand-casting process, providing the detachable die cavity required for powder compaction operations.

Component sub-assembly and testing: each subsystem (H-frame, hydraulic jack, spring assembly, heating mantle) was independently evaluated for structural and functional adequacy prior to integration.

Final assembly: all components were joined into permanent configuration, with bolted connections torqued to specification and welded joints inspected for integrity.

Surface preparation and finishing: rough edges were ground and polished; the entire machine was cleaned, dried, and primed with red-oxide primer for corrosion protection before application of a final coat of industrial oil-based paint.

3. Results

A. Structural Fabrication Outcomes

The completed H-frame exhibited precise dimensional conformity to design specifications, with height and width of 725 mm and 380 mm respectively, fabricated from 75 × 40 mm C-channel sections. The base support plate matched these dimensions, providing a stable and well-balanced foundation. Post-fabrication stability assessment conducted by evaluating the machine's angle of tipping and confirming that the centre of gravity lay well within the frame footprint demonstrated excellent structural stability under both static and dynamic loading conditions.

The two helical return springs, each with a free length of 230 mm, were installed between the upper and lower platens. Under repeated jack cycling, the springs returned the lower platen consistently and without observable lateral drift confirming correct spring rate selection and alignment. No permanent deformation of the H-frame, platens, or column sections was recorded following the full load test sequence.

B. Hydraulic System Performance

The hydraulic system underwent a two-phase testing protocol.

In the first phase, the system was primed and pressurised under no-load conditions and left to stand for two hours. No pressure loss or hydraulic fluid seepage was observed, confirming the integrity of all hydraulic connections, fittings, and seals.

In the second phase, the lower platen was subjected to a compressive load of 10 kN applied via the two helical compression springs (spring constant: 9 N/mm each, arranged in parallel) compressed axially to 100 mm. The assembly was held under load for two hours. The lower platen remained stationary throughout this period, with no downward displacement recorded, conclusively confirming the absence of hydraulic fluid leakage and the adequacy of system pressure retention under sustained loading.

Performance evaluation using mild steel test specimens demonstrated the press's multi-operational capability. A mild steel plate (220 mm × 70 mm × 20 mm) was successfully bent at a gauge pressure of 50 bar, while a thinner plate (290 mm × 225 mm × 3 mm) began bending at 15 bar and achieved maximum deformation at 20 bar. Engine sleeve pressing (inner diameter 85 mm, outer diameter 89 mm) into an automotive cylinder block was accomplished at 15 bar confirming that the press delivers consistent and controllable force output across a range of operational pressures.

C. Thermal System Performance

The heating mantle achieved stable operating temperatures within the 120–150 °C range required for thermoplastic powder compaction. Initial thermal validation was conducted using high-density polyethylene (HDPE) powder as a proxy workpiece material. The powder was loaded into the cast mold, placed on the lower platen, and subjected to simultaneous hydraulic compression and thermal energy input. Upon heating to 120–150 °C and concurrent application of hydraulic pressure via the jack, the HDPE powder consolidated satisfactorily into a dense compact confirming both the functionality of the heating system and the adequacy of thermal-mechanical integration.

The thermocouple system provided stable, repeatable temperature readings throughout all trials, with no observed drift or calibration error.

D. Multi-Functional Operational Capability

Beyond powder compaction, the hydraulic hot press demonstrated satisfactory performance across a range of workshop operations, including:

Punching and hole perforation: using a punch attached to the lower platen chuck, clean, accurate holes were produced in flat plates with minimal burring.

Bending: controlled application of hydraulic force enabled gradual, accurate bending of steel plates to desired curvature without spring-back cracking.

Stamping and impression: the press delivered consistent pattern impressions on soft substrate materials.

Engine component assembly: sleeve pressing into engine block bores was performed with precision at 15 bar, verifying the press's utility for automotive assembly and maintenance applications.

Deep and shallow drawing: initial trials of cup drawing using flat sheet blanks confirmed the press's suitability for forming operations when appropriate dies are employed.

E. Economic Analysis

The total fabrication cost of the hydraulic hot press, including all materials, consumables, and manufacturing processes, amounted to approximately ₦398,440 (equivalent to approximately USD 2,000 at the prevailing exchange rate at the time of fabrication). This represents a cost saving of about 87% compared to the equivalent imported machine, which typically retails between USD 5,000 and USD 15,000 exclusive of shipping, duties, and importation logistics. This substantial cost differential highlights the economic case for local fabrication as a viable strategy for equipping workshops and engineering laboratories in resource-constrained settings.

F. Alignment with Sustainable Development Goals

This project directly supports United Nations Sustainable Development Goal 1 (No Poverty) by reducing the financial burden of workshop equipment procurement on small and medium-scale enterprises, and Goal 9 (Industry, Innovation, and Infrastructure) by promoting indigenous manufacturing capability, local value addition, and technology transfer. The use of locally sourced raw materials and standard manufacturing processes further reduces dependence on imported equipment, strengthens local supply chains, and creates skilled employment opportunities in fabrication and maintenance.

4. Conclusion

This study has demonstrated the successful design, fabrication, testing, and performance validation of an 80-tonne uniaxial hydraulic hot press using locally sourced materials and standard engineering manufacturing processes. It was observed that the H-type frame, fabricated from A36 hot-rolled C-channel steel, provided the requisite structural rigidity and dimensional stability to safely sustain the 80-tonne rated load without observable deformation, weld failure, or instability. The hydraulic actuation system comprising the integrated 80-tonne jack, calibrated pressure gauge, and helical return springs delivered consistent, controllable compressive force across the operational pressure range tested (15–50 bar), with zero evidence of fluid leakage under sustained loading conditions. The thermal subsystem, incorporating an electric resistance heating mantle achieved operational temperatures adequate for polymer powder sintering and thermoplastic hot pressing, as validated by successful HDPE compaction trials. In multi-functional performance evaluation, the press demonstrated satisfactory multi-functional performance, executing bending, punching, sleeve pressing, stamping, and drawing operations on metallic workpieces at pressures consistent with design predictions. The total local fabrication cost of approximately ₦398,440 (USD 2,000) represents a saving of about 87% relative to equivalent imported equipment, establishing a compelling economic rationale for indigenous workshop machine production. Finally, the project is aligned with UN Sustainable Development Goals 1 and 9, contributing to poverty reduction and industrial innovation through the promotion of local manufacturing capability and reduced import dependency. Future work will focus on the integration of an automated digital pressure and temperature control system to enhance operational precision, reduce operator dependency, and extend the machine's applicability to research-grade powder metallurgy and composite fabrication. The development of interchangeable die systems for specialized forming operations including equal channel angular pressing (ECAP) and isostatic compaction geometries would further broaden the machine's research and industrial utility. Structural optimization using finite element analysis, as demonstrated in comparable studies (Muni and Amarnath, 2011; Kamate, 2016), is also recommended to identify opportunities for weight reduction without compromising load-bearing performance.

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