FACTORS INFLUENCING BIOCHAR'S POTENTIAL AS A CARBON CAPTURING AND SEQUESTERING CONSTRUCTION MATERIAL

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ABSTRACT

Biochar is a relatively well-known soil enhancement material. It has recently been investigated as a building material. While work on deploying biochar for road construction has been done, there is an emerging trend of using biochar as a concrete admixture. In comparison, using biochar in this manner will reduce greenhouse gas emissions more than capturing and sequestering carbon through mineralization and deployment in construction. The use of biochar-containing construction materials to capture and then lock atmospheric carbon dioxide in buildings and structures has the potential to reduce greenhouse gas emissions by 25%. The focus of this review was on assessing biochar's capacity for carbon adsorption, which is affected by factors such as pyrolysis conditions (specifically, pyrolysis temperature, heating rate, and pressure) and activation methods (and without surface modification). There are gaps in the current literature, and important areas for future research have been proposed.

Keywords*: Biochar; Pyrolysis; Construction material; Activation; Adsorption*

INTRODUCTION

The Possibility of Using Biochar as a Building Material :

Direct air capture of carbon dioxide (CO_2) is one of the most recent approaches to mitigating climate change and developing materials capable of capturing CO_2 via adsorption is regarded as one of the viable alternatives. As a carbon removal method ,Adsorption and capture are relatively simple processes with low associated costs significantly lower than commercial processes . Biochar, with its strong affinity for non-polar substances and high surface area, can be a potential material to capture and store CO_2 by adsorption in its pores. It has been widely applied as soil conditioner and as a treatment material for wastewater, but research on its application as a construction material is still sparse. Because of its ability to capture CO_2 from air, biochar has the potential to contribute to lowering of carbon emission in the building industry if it is used as a construction material.

Biochar as a carbon capture and sequestration tool :

- (CCS) strategy is restricted to agricultural applications (as a type of soil improver) and as an adsorbent material for post-combustion CCS from exhaust.

- When biochar is added to soil, it can help to keep carbon in a chemically stable and inert form for an extended period of time.

- Factors that make biochar superior as a soil enhancer can, in fact, contribute to construction. For example, biochar's high pH and high water-retention rate cause it to absorb some of the mixing water during concrete mixing, reducing the amount of free water in the concrete.

The goal of this study is to provide a critical review of the most recent explorations of using biochar as a construction material; specifically, key production factors that determine the physical and chemical properties of biochar relevant to carbon adsorption (including temperature, pressure, heating rate, and residence time) are synthesised and analysed.

IMPACT OF PROCESS PARAMETERS ON BIOCHAR :

Biochar is a stable carbon-rich organic compound that is commonly produced through the pyrolysis of biomass derived from agricultural, municipal, domestic, or organic waste. Pyrolysis is a process that involves heating biomass in the absence of oxygen to produce three main products: bio-oil, biogas, and biochar. The structure of biochar, specifically its total surface area, determines its ability to absorb CO_2. Among the various methods that can influence the structure of biochar produced, The pyrolysis temperature, rate, and pressure are all taken into account to be the most important variables influencing char morphology. Furthermore, pyrolysis temperature and heating rate have a significant impact on the distribution of char, gas, and liquid during pyrolysis. The energy supplied is sufficient to release the volatiles from biomass at higher temperatures. Furthermore, at high temperatures, biochar undergoes a secondary reaction, which increases the yield of gas and liquid (bio-oil) while decreasing the proportion of char.

The key findings on the effect of pyrolysis temperature on char yield are summarised in Table 2.

Table 2. Research Findings of Effect of Pyrolysis Condition on Char Yield

Biomass	Pyrolysis condition	Char yield (%)	Reference
Pine	300℃; slow pyrolysis	58	Shabangu et al. (2014)
	450℃; slow pyrolysis	26	
Sewage slug	Pyrolysis temperature (T): 350℃; heating rate (R): 30℃/min	52	Sánchez et al. (2009)
	T: 950℃; R: 30℃/min	39	
Corn stover	Pyrolysis temperature: 500℃ in fluidized bed	16.80	Mullen et al. (2010)
Corn cobs		18.90	
Switchgrass (Panicum virgatum)	T: 600℃; R: 6℃/min; 20 min at 600℃	25	Imam and Capareda (2012)
Soybean cake	T: 550℃; R: 300℃/min	21	Uzun et al. (2006)
Rice husk	T: 400℃ and residence time (t) of 5 s (at 500℃)	33	Williams and Nugranad (2000)
	T: 600℃; t: 5 s at (500℃)	25.50	
Spruce wood (Picea orientalis)	T: 750℃	32.40	Demirbas (2010)
Hardwood shavings	Fast pyrolysis, residence time <5 s and pyrolysis temperature at 500℃	12.70	Agblevor et al. (2010)
Douglas fir wood	T: 350℃; R: 190℃/min	38.30	Suliman et al. (2016)
Douglas fir bark		47.90	
Hybrid poplar wood		31.90	
Olive husk	T: 200℃ (approximately); R: 10℃/s	44.50	Demirbas (2004)
	T: 975℃; R: 10℃/s	19.40	
Safflower seed press cake	T: 400℃; R: 10℃/min	34.18	Angın (2013)
	T: 400℃; R: 30℃/min	30.50	
	T: 400℃; R: 50℃/min	28.70	

THE IMPORTANCE OF PYROLYSIS TEMPERATURE :

The degree to which the physical structure of biomass is modified during pyrolysis is influenced by the extent to which cellulose, hemicellulose, and lignin decompose. At different temperatures, cellulose, hemicellulose, and lignin decompose. Pyrolysis temperature was found to affect the physicochemical\sproperties of biochar such as elemental composition, surface functional\sgroups, surface area, and stability (Sun et al. 2014; Zhang\set al. 2015; Shaaban et al. 2013; Yuan et al. 2014). Zhang et al. reported similar results regarding the effect of pyrolysis temperature on elemental composition (2015). According to some research groups, high pyrolysis temperatures are to blame for the loss of structural complexity in biochar. This effect is more pronounced in cases where pyrolysis temperature \sis same as ash melting point of the feedstock. Melting and swelling are more common in biomass containing more volatile substances. For example, Lua et al. (2004) discovered that increasing the temperature of pistachio nut-based biochar from 500 to 800°C resulted in a decrease in surface area.

THE IMPORTANCE OF HEATING RATES AND RESIDANT TIME :

The heating rate of pyrolysis affects both chemical properties (such as elemental composition) and physical properties (such as surface area and char morphology). Bruun et al. (2012), for example, discovered that biochar produced by fast pyrolysis had significantly lower carbon content and higher oxygen content than char produced by slow pyrolysis. When corn stover was used as feedstock, Brewer et al. (2012) observed a similar trend. Cetin et al. (2004) discovered that when pyrolysis is performed at low heating rates, the morphology of char does not change because the natural porosity allows volatiles to be removed. Longer vapour residence time and lower temperature can result in higher biochar production (Encinar et al. 1996). A longer residence time promotes the repolymerization reaction. of biomass constituents, resulting in an

increase in biochar yield (Park et al. 2008). According to Kim et al. (2011a), increasing residence time from 1.2 to 7.7 s at a constant temperature (500°C) increased When yellow poplar is grown, the yield of biochar increases while the yield of bio-oil decreases. The wood had been pyrolyzed. According to Mohamed et al. (2013), residence Although time has an effect on char yield, it is not significant has an impact on the composition of bio-oil and gaseous products In general The effect of residence time on biochar production is not obvious. because biochar yield and properties are frequently dominated other manufacturing parameters, such as pyrolysis temperature.

THE IMPORTANCE OF PYROLYSIS PROCESS :

The morphology of biochar particles produced is influenced by pyrolysis pressure. Cetin et al. (2004), for example, discovered that biochar particles produced at 0.50 MPa (5 bar) had larger cavities and thinner cell walls than biochar produced at atmospheric pressure. Larger particles with perforations formed when pressure was increased to 10 and 20 bar. Pyrolysis pressure has an effect on surface area and biochar reactivity. Cetin et al. (2004) discovered that the surface area measured by passing both N_2 and CO_2 decreases slightly as the temperature rises. in pyrolysis pressures ranging from 1 to 20 bar Newalkar et al. (2014) developed a different observation that as CO_2 surface area increased, It increased when pressure increased from 5 to 10 bar. The bar was raised from 10 to 20. This was only in cases where pyrolysis was used The temperature was less than 1,000 degrees Celsius. Mesopores' Contribution and macropores at a pressure of 10 bar, which may be because of pore widening under pressure, resulting in micropores Pores combine to form larger ones.

Table 3. Summary of Effect of Pyrolysis Conditions on Properties of Biochar

Biomass/feedstock	Preparation of biomass	Preparation process	Preparation temperature (°C)	Heating rate	Pyrolysis pressure	Key observations	References
Rubberwood saw dust	Sieved to remove big chunks and dried at 105°C	Pyrolysis	300, 500, and 700°C	5°C/min	—	(1) BET surface area increased drastically when temperature was raised from 500 to 700°C. (2) More micropores and higher pore volume were created at 700°C.	Shaaban et al. (2013)
Saw dust	Dried at 110°C for 24 h and ground to 2–3 m size	Pyrolysis	450–850°C at interval of 100°C	30°C/min	20 bar	(1) Surface area of 220 m²/g was recorded between 550 and 850°C. (2) Highest carbon content in biochar was noted at 750°C beyond which it decreased. (3) Maximum CO_2 adsorption capacity (18 mg/g) was recorded at 650°C beyond which it decreased by about 4–5%.	Ghani et al. (2013)
Hickory wood bagasse bamboo	Samples sieved to 0.5–1 m size, washed and dried at 80°C for 24 h	Pyrolysis / Hydrothermal carbonization	300, 450, and 600°C 200°C	10°C/min	—	(1) With rise of temperature from 200 to 600°C, carbon content in biochar was raised from 53 to 83%. (2) Surface area of biochar made at 600°C increased 30 times compared to those made at 450°C. (3) Thermal stability of char made by dry pyrolysis was higher than those made by hydrothermal carbonization.	Sun et al. (2014)
Pine wood (*Pinus sieda*)	Pine logs were debarked and chipped. Particle size of 180–250 μm was used for pyrolysis	Pyrolysis	600–1,000°C	10^3–10^4°C/min	5–20 bar	(1) With increase in pressure, char particles tend to become more spherical. Swelling increased with decrease in externally applied pressure. (2) Highest micropore area was recorded at 1,000°C when pyrolysis pressure was kept at 5 bar. (3) Graphitization of char increases with pressure at high temperature and then plateaus.	Newalkar et al. (2014)
Wheat straw	Feedstock was ground to 1.4 mm size	Pyrolysis (slow and fast)	525°C	Slow: 6°C/min with 2 h hold time at peak temperature Fast: initial heating rate between 250 and 1,000°C/s	—	(1) Carbon content in biochar made by slow pyrolysis was about 20% higher. (2) Surface areas produced by fast and slow pyrolysis were comparable but of lower magnitudes (1.6 and 0.6 m²/g, respectively).	Bruun et al. (2012)
Douglas fir wood Douglas fir bark hybrid poplar wood	Feedstock was air dried and ground to below 2 mm size. Further ball milled to 590 μm size	Pyrolysis	350–600°C at increment of 50°C	190°C/min	—	(1) At elevated temperature (550 and 600°C), Douglas fir wood had highest percentage of carbon. (2) Douglas fir wood had highest percentage of larger micropores, whereas it was concluded that for all char samples entrance pore size was smaller than 1 nm.	Suliman et al. (2016)
Safflower seed press cake	Air dried and screened to obtain particle size of 1.8 mm	Pyrolysis	400–600°C at increment of 50°C	10, 30, and 50°C/min	—	(1) With increase in temperature from 400 to 500°C, micropore volume, BET surface area, and total pore volume increased significantly. Above 500°C, micropore volume was decreased, which may be due to pore expansion due to heating. (2) With increase in heating rate, surface area and pore volume decreased probably due to accumulation of volatiles at high heating rate. (3) The effect of heating rate was more prominent at lower pyrolysis temperature.	Angın (2013)

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BIOCHAR SURFACE MODIFICATION AND ACTIVATION :

While controlling production parameters like heating rate and pyrolysis temperature, allowing for the control of porosity and surface Biochar activation is a very common practise in the field of biochar for industrial applications in order to achieve even greater adsorption capacity Activation increases the fraction of micropores and mesopores. Consequently, the total surface area of biochar is increased (Bansal et al. 1998)The extent of influence, however, is determined by the feedstock used Schröder et al. (2007), for example, discovered a significant difference in surface area following activation of biochar made from various biomasses including walnut, nutshell, rice straw, wheat straw, and wheat straw shells. Specifically, nutshell biochar activation resulted in high surface area in the 1,000–1,300 m2/g range. After chemical activation, the surface area and pore area increased to 836 and 753.5 m2=g, respectively. The findings also suggested that an increase in temperature caused by steam activation increased surface area but decreased product yield. Stavropoulos (2005) reported similar results with physically (steam) activated olive kernel carbons; a BET surface area of 1; 339 m2=g was observed after 1 hour of activation at 800°C; this value increased to a maximum of 3; 049 m2=g after 4 hours of activation at 900°C.

SURFACE MODIFICATION AND/OR ACTIVATION OF CO2 ADSORPTION :

In an effort to reduce the activation process's energy intensity, Plaza et al. (2014) investigated the impact of single-step oxidation on Char textural characterization and adsorption capacity Olive stone and almond shell They discovered that biochar treatment with a low oxygen concentration in the 3–5% range at temperature Micropores can be formed at temperatures ranging from 550 to 650°C. under ambient conditions, conducive to CO2 capture Biochar is a product. capable of absorbing a variety of gases other than CO2, such as water vapor as well as nitrogen; thus, in order to be an effective carbon adsorbent, it must CO2 selectivity should be high. Surface modification with functional groups can improve biochar's CO2 adsorption capacity. Xiong et al. (2013) modified biochar made by pyrolyzing cotton stalk with CO2 and ammonia. Temperatures ranging from 500 to 900°C were tested for modifying. CO2 modification was discovered to significantly increase surface area, with the highest value at 800°C, approximately 610.04 m2=g. By introducing nitrogen-containing compounds on the surface of the biochar, ammonia modification increased alkalinity and thus affinity for CO2. When the char was modified at temperatures of 500, 600, and 800°C, the adsorption capacity was tested at 20 and 120°C. As previously stated, micropores dominate CO2 adsorption at room temperature, so amine impregnation in activated carbon is unnecessary. Adsorption at low temperatures is preferred. Table 4 summarises key findings on biochar adsorption capacity. with and without surface activation or treatment.

Table 4. Summary of Findings on CO$_2$ Adsorption Capacity of Char with and without Activation

Treatment	Biomass/feedstock	Pyrolysis condition	Activator/surface treatment agent	Activation condition	Surface area for adsorption (m²/g)	Micropore volume	Adsorption temperature (°C)	Carbon sequestered by CO₂ adsorption (mmol/g), key findings	Carbon sequestered as fixed carbon by conversion of biomass to biochar (% of dry ash-free basis)	References
Without activation	Saw dust	Pyrolysis temperature: 450–850°C at increment of 100°C Residence time: 60 min	—	—	200	—	25°C	Highest adsorption of 0.41 mmol/g at 650°C Decreased by 4.10% and 4.80% at 750 and 850°C	Maximum of 97.3 ± 2% in biochar prepared at 750°C	Ghani et al. (2013)
With surface treatment and/or activation	Cotton stalk	Pyrolysis temperature: 600°C	Ammonia	Activator (ammonia or CO₂) passed over heated char at 500–900°C at increment of 100°C	434.92	0.19 cm³/g	20 and 120°C	(1) Maximum adsorption by CO₂ (99.50% purity; flow rate: 24 ml/min at STP) modified char (at 800°C): 2.05–2.30 mmol/g of CO₂ (2) Maximum adsorption of NH₃–modified char (at 900°C): 1.81 mmol/g of CO₂	—	Xiong et al. (2013)
			CO₂		610.04	0.24 cm³/g				
	Bamboo	Pyrolysis temperature: 500°C and heating rate: 5°C/min	Potassium hydroxide (KOH)	KOH solution was used at different KOH-to-carbon mass ratios of 1, 2, 3, 4, and 5. They were activated at 600 and 700°C	2,000 (maximum adsorption at this surface area)	0.39 cm³/g for pores ranging from size 0.33 to 0.82 nm	0 and 25°C	Maximum CO₂ uptake of 7 mmol/g recorded for char prepared at 600°C activation temperature with KOH-to-carbon ratio of 3	—	Wei et al. (2012)
	Almond shell	Carbonized at 600°C to obtain char yield of 24%	CO₂	CO₂ passed over char at 700°C	1,090	0.19 cm³/g	25°C	2.70 mmol/g	93.60% at 700°C	Plaza et al. (2010)
			Ammonia	Treatment with ammonia at four different temperatures: 400, 600, 800, and 900°C	448	0.20		Char treated with ammonia at 800°C had highest CO₂ uptake: about 2.07 mmol/g	91.10% at 400°C	
	Petroleum pitch	—	Potassium hydroxide (KOH)	—	3,100	1.42	0°C 25°C 50°C	8.60 mmol/g 4.2 mmol/g 2.26 mmol/g	— —	Wahby et al. (2010)
	Palm shell	—	Ammonia modification without peroxidation	Ammonia charged at 75 cm³/min and sample soaked for 2 h	889	0.442	30°C/105°C	At 30°C: 1.67 mmol/g At 105°C: 0.70 mmol/g	89.60%	Shafeeyan et al. (2011)
			Ammonia modification with preoxidation	Air introduced at 400°C and sample held for 2.5 h before subjecting to ammonia	826	0.396		Oxidation may decrease micropore volume and reduce site for CO₂ capture	92.80%	

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CONCLUSION AND OF FUTURE RESEARCH :

As discussed in this review, proper feedstock preparation and control of pyrolysis process parameters such as pyrolysis temperature, pressure, and heating rate are critical for producing biochar with suitable physical properties for CO2 adsorption Although there have been a number of studies on the use of biochar to reduce ageing in bitumen or increase pavement durability, evaluation of its potential as a carbon-sequestering construction material is very limited. Furthermore, adsorption of greenhouse gases on biochar-coated walls may not be useful in the long run because, given the small amount used, saturation will occur quickly. It is also inefficient to replace wall coatings on a regular basis to ensure frequent adsorption. As a result, future research should focus on this issue. Biochar could be used in concrete mixtures for buildings and civil engineering structures. Biochar, for example, can be saturated with CO2 before being mixed into concrete, effectively locking the captured CO2 within these buildings and structures. Such a concept could pave the way for massive amounts of greenhouse gases to be captured and stored indefinitely. However, it is critical to investigate whether biochar containing adsorbed CO2 may cause carbonation-related durability issues in reinforced concrete. High temperatures caused by heat of hydration in fresh concrete may desorb some CO2 from biochar.Desorbed CO2 molecules may form calcium carbonate in fresh concrete, which may be beneficial by reducing porosity, but carbonation at a later stage may be detrimental to reinforced concrete durability by corroding the embedded reinforcement bars. In addition to testing the durability and structural properties of biochar-containing concrete, the associated economic, environmental, and social benefits of these new materials should be investigated. It will be especially useful to investigate how incorporating biochar into buildings and structures can result in more holistic sustainability benefits beyond climate change mitigation (Gunawansa and Kua 2014; Kua and Gunawansa 2010; Kua and Koh 2012; Lutchmeeduth et al. 2010; Kua and Ashford 2004). Methods of sustainability assessment, such as lifecycle assessment, can also be investigated for ways to improve the lifecycle performance of these new materials (Kua 2013a, b, 2015) Kua et al., 2014; Kua et al., 2016). Finally, test standards for biochar applications in building construction and other civil engineering structures should be developed.

Given the emphasis on sustainable construction and current advances in biochar research, it may be a reasonable expectation that biochar will be used more widely as a construction material, not only as a waste management strategy but also for CCS. However, before that future can be realised, the previously mentioned technological and technological issues must be addressed.

REFERENCES

- *Abe, I., Hitomi, M., Ikuta, N., Kawafune, I., Noda, K., and Kera, Y. (1995). "Humidity-control capacity of microporous carbon." J. Urban Living Health Assoc., 39(6), 333–336.*
- *Agblevor, F. A., Beis, S., Kim, S., Tarrant, R., and Mante, N. (2010). "Biocrude oils from the fast pyrolysis of poultry litter and hardwood." Waste Manage., 30(2), 298–307.*
- *Ahmad, S., Khushnood, R. A., Jagdale, P., Tulliani, J.-M., and Ferro, G. A. (2015). "High performance self-consolidating cementitious composites by using micro carbonized bamboo particles." Mater. Des., 76, 223–229.*
- *Alaya, M., Girgis, B., and Mourad, W. (2000). "Activated carbon from some agricultural wastes under action of one-step steam pyrolysis." J. Porous Mater., 7(4), 509–517.*

- *Amonette, J. E., and Joseph, S. (2009). "Characteristics of biochar: Microchemical properties." Chapter 3, Biochar for environmental management: Science and technology, J. Lehmann and S. Joseph, eds., Earthscan, London, 33–52.*
- *Angın, D. (2013). "Effect of pyrolysis temperature and heating rate on biochar obtained from pyrolysis of safflower seed press cake." Bioresour. Technol., 128, 593–597.*
- *Antal, M. J., and Grønli, M. (2003). "The art, science, and technology of charcoal production." Ind. Eng. Chem. Res., 42(8), 1619–1640.*
- *Arenillas, A., Smith, K., Drage, T., and Snape, C. (2005). "CO2 capture using some fly ash-derived carbon materials." Fuel, 84(17), 2204–2210.*
- *Azargohar, R., and Dalai, A. (2008). "Steam and KOH activation of biochar: Experimental and modeling studies." Microporous Mesoporous Mater., 110(2), 413–421.*
- *Bansal, R. C., Donnet, J., and Stoeckli, F. (1998). Active carbon, 1988, Marcel Dekker, New York.*
- *Boateng, A. (2007). "Characterization and thermal conversion of charcoal derived from fluidized-bed fast pyrolysis oil production of switchgrass." Ind. Eng. Chem. Res., 46(26), 8857–8862.*
- *Brewer, C. E. (2012). "Biochar characterization and engineering." Ph.D. dissertation, Iowa State Univ., Ames, IA.*
- *Brewer, C. E., et al. (2014). "New approaches to measuring biochar density and porosity." Biomass Bioenergy, 66, 176–185.*
- *Bridgwater, A. (2003). "Renewable fuels and chemicals by thermal processing of biomass." Chem. Eng. J., 91(2), 87–102. Brown, R. A., Kercher, A. K., Nguyen, T. H., Nagle, D. C., and Ball, W. P. (2006). "Production and characterization of synthetic wood chars for use as surrogates for natural sorbents." Org. Geochem., 37(3), 321–333.*
- *Brownsort, P. A. (2009). "Biomass pyrolysis processes: Performance parameters and their influence on biochar system benefits."Ph.D. dissertation, Univ. of Edinburgh, Edinburgh, Scotland.*
- *Bruun, E.W., Ambus, P., Egsgaard, H., and Hauggaard-Nielsen, H. (2012). "Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics." Soil Biol. Biochem., 46, 73–79. Cetin, E., Gupta, R., and Moghtaderi, B. (2005). "Effect of pyrolysis pressure and heating rate on radiata pine char structure and apparent gasification reactivity." Fuel, 84(10), 1328–1334.*

- Srinivas K, Vijaya SK, Jagadeeswari K. Concrete with ceramic and granite waste as coarse aggregate. Materials Today: Proceedings. 2020 Aug 29.

- Priyanka ML, Padmakar M, Barhmaiah B. Establishing the need for rural road development using QGIS and its estimation. Materials Today: Proceedings. 2020 Sep 12.

- Padmakar M, Barhmaiah B, Priyanka ML. Characteristic compressive strength of a geo polymer concrete. Materials Today: Proceedings. 2020 Sep 20.

- George R, Patel IB, Rathod KT. Growth and photoluminescence study of nickel sulfate doped Zinc tris-Thiourea Sulfate (ZTS) crystal. Materials Today: Proceedings. 2020 Sep 11.

- M.PADMAKAR, BRAMAIAH.B, SRINIVAS.K, LAL MOHIDDIN .SK. MIX DESIGN FOR RIGID PAVEMENT BY USING RECYCLED AGGREGATE WITH THE ADDITION OF ADMIXTURE. JCR. (2020), 7(13): 2187-2193. doi:10.31838/jcr.07.13.340

- KARRI SRINIVAS, M.PADMAKAR, B.BARHMAIAH, SATHI KRANTHI VIJAYA. EFFECT OF ALKALINE ACTIVATORS ON STRENGTH PROPERTIES OF METAKAOLIN AND FLY ASH BASED GEOPOLYMER CONCRETE. JCR. (2020), 7(13): 2194-2204. doi:10.31838/jcr.07.13.341

- BORIGARLA BARHMAIAH, K.SRINIVAS, M.PADMAKAR , LAL MOHIDDIN .SK. PEAK HOUR ANALASIS AND EFFECT OF TRAFFIC COMPOSITION ON CAPACITY OF ARTERIAL ROADS. JCR. (2020), 7(13): 2205-2213. doi:10.31838/jcr.07.13.342

- Maddala P. Pushover analysis of steel frames (Doctoral dissertation).

- Vummadisetti S, Singh SB. Buckling and postbuckling response of hybrid composite plates under uniaxial compressive loading. Journal of Building Engineering. 2020 Jan 1;27:101002.

- Vummadisetti S, Singh SB. Postbuckling response of functionally graded hybrid plates with cutouts under in-plane shear load. Journal of Building Engineering.;33:101530.
- [19] Study of activation energy for KDP crystals in etchants with citric and tartaric acids
- R George, IB Patel, P Maddala, S Karri
- Materials Today: Proceedings
- [20] Growth studies for calcium phosphates (Brushite) crystals in gel method
- R George, IB Patel
- ACTA CIENCIA INDICA PHYSICS 28 (3), 137-140
- [21] STUDY OF ACTIVATION ENERGY FOR KDP AND DOPED KDP SINGLE CRYSTALS USING THERMO GRAVIMETRIC ANALYSIS