University of Zurich[UZH]

19th International Congress on Marine Corrosion and Fouling

Florida Institute of Technology

A Holistic Ranking of Construction Materials for Marine Environments in the Long Term Future

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1. Introduction

Population Growth and Urbanisation

Development of new cities and growth of existing cities into megacities

Global Warming Effects

Rising sea levels threaten major coastal cities and entire island nations

Increasing amount of infrastructure exposed to marine environment

Durable construction materials required

Assessment of material availability necessary before engaging in costly R&D to improve materials

Long-term availability of various materials uncertain

Global Resource Depletion

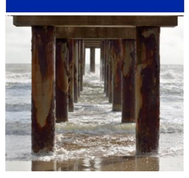
2. Ranking Methodology

Goal:

Identify **structural materials** that are most suitable for **sustainable** marine construction in the **long-term future** and **identify research areas** that may provide significant improvements.

- Durability assessed for materials in **splash-zone** without additional protection methods
- **Functional unit** for material comparison related to compressive strength

Ranking Categories:

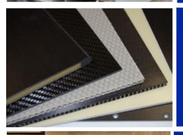
Durability in the Marine Environmnet	Economics & Costs (Life Cycle Costs)	Sustainability & Environmental Impact	Future Availability (Supply & Demand)
			

Ranking Score:

Individual attributes ranked 1-5.

- **Values precisely defined** for each attribute
- Individual scores aggregated using **weighting factors**

Selected Materials:

	**Concrete**	**Cement** • Blended • Alkali activated (Geopolymer) • Calcium Sulfoaluminate	**Reinforcement** • Steel • Stainless Steel • GFRP • CFRP
	**Metals**	• Carbon Steels • Stainless Steels • Aluminum Alloys • Titanium Alloys • Nickel Alloys	
	**Composites**	**Matrix** • Thermoset • Thermoplastic	**Fiber** • Glass • Carbon • Basalt • Natural C4
	**Timber**	• Softwood • Non-Tropical Hardwood • Tropical Hardwood	

Data Aquisition:

- Discussions with experts
- Literature research
- Database calculations

USGS science for a changing world

econvent

3. Material Ranking

	Attribute	Weight	Highest Ranked: Non-Tropical Hardwood	Blended Cement: Steel	Blended Cement: GFRP	Blended Cement: CFRP	Geopolymer: Steel	Geopolymer: GFRP	Geopolymer: CFRP	Softwood	Carbon Fiber Thermoset	Carbon Steel	Lowest Ranked/Criticallity Issues: Natural Fiber Thermoplastic	Duplex Stainless Steel	Nickel Alloys	Titanium Alloys
Durability	Corrosion Resistance	3	5	4	5	5	4	5	5	5	5	1	5	4	5	5
	Resistance to Biological Degradation	3	2	5	5	5	5	5	5	1	5	3	4	3	5	5
	Fatigue Resistance	1	4	4	4	4	4	4	4	4	4	3	3	3	2	3
	Resistance to Stress Corrosion Cracking	2	3	3	4	5	3	4	5	3	5	2	2	4	5	5
	UV Resistance	1	4	5	5	5	5	5	5	4	3	5	1	5	5	5
	Moisture Resistance	3	2	5	4	5	5	4	5	1	4	5	1	5	5	5
	Cat. Score		3.15	4.38	4.54	4.92	4.38	4.54	4.92	2.69	4.54	3.00	2.92	4.00	4.77	4.85
Economics & Costs	Material Costs	3	4	5	4	5	5	5	5	5	3	5	1	2	1	2
	Ease of Manufacture	1	2	5	4	4	5	4	4	3	4	4	3	3	4	3
	Maintenance Cost - Vulnerability	3	3	4	4	4	4	4	4	3	3	4	3	4	4	4
	Maintenance Cost - Repairability	3	4	4	4	4	4	4	4	4	4	5	3	4	5	2
	Reaction to Fire	2	2	5	5	5	5	5	5	2	3	5	1	5	5	5
	Resistance to Fire	2	3	4	4	4	5	5	5	3	3	2	1	2	2	5
	Performance Uncertainty	1	5	4	2	3	2	1	1	5	3	5	1	4	4	5
	Projected Price Developments	1	1	3	3	3	5	5	5	1	3	3	3	2	1	2
	Cat. Score		3.19	4.31	3.94	4.19	4.44	4.31	4.31	3.44	3.25	4.25	2.00	3.31	3.31	3.38
Sustainability	Raw Material Renewability	2	5	1	1	1	1	1	1	5	1	1	3	1	1	1
	Recycling Approach	3	5	2	1	1	1	1	1	5	2	5	2	5	5	5
	Impact of Production on Human Health	2	5	4	5	5	4	5	5	5	4	2	2	1	1	1
	Impact of Production on Ecosystems	2	2	5	5	5	5	5	4	1	4	2	2	1	1	1
	Impact of Production on Resources	2	5	4	5	5	4	5	5	5	3	1	2	1	1	1
	Cat. Score		4.45	3.09	3.18	3.18	2.82	3.18	3.00	4.27	2.73	2.45	2.18	2.09	2.09	2.09
Future Availability	Reserves/Production Ratio of Raw Materials	2	5	3	3	3	3	3	3	5	3	2	3	1	2	1
	Resources/Production Ratio of Raw Materials	3	5	5	4	4	5	4	4	5	4	5	4	2	2	5
	Geographical Distribution of Reserves	3	5	4	5	5	4	5	5	5	5	4	5	1	4	1
	Potential for Restrictive Government Regulation	2	5	5	4	4	4	4	4	5	4	5	4	2	2	5
	Development of Recycling Infrastructure	3	5	4	3	3	4	3	3	5	4	5	3	5	5	5
	Projected Growth of Competing Industries	2	4	5	3	3	3	3	3	4	2	5	3	1	1	1
	Ease of Production Increase	1	2	4	3	3	2	2	2	2	3	5	2	3 !	2 !	2 !
	Cat. Score		4.69	4.31	3.69	3.69	3.81	3.63	3.63	4.69	3.75	4.44	3.63	2.19 !	2.81 !	3.06 !
	TOTAL		4.06	4.03	3.81	3.93	3.79	3.83	3.88	3.93	3.63	3.56	2.89	2.76	3.18	3.30

Areas where **anti corrosion and fouling technologies** can provide long term benefits

Areas where **policy measures** are essential for increasing sustainability

4. Conclusion

Timber as a promising renewable resource may become more important

- Development of strategies for protection of timber from biological attack is essential
- Expansion of managed forests required to ensure sufficient availability of sustainably harvested timber.

Reinforced concrete and steel are promising materials with widespread availability

- Development of environmently friendly methods for corrosion protection of steel necessary
- Increased funding and adaption of regulations may enable more widespread application of alternative cement and reinforcement types

Increasing recycling rates is essential to guarantee long-term availability of all materials

- Policy measures required to improve waste collection processes and recycling infrastructure
- Technological developments necessary to allow for separation of individual material constituents

5. Outlook

Application of framework to materials including protective coatings

- Evaluation of sustainability and long-term potential of different approaches
- Prioritize proposed R&D projects

Addition of newly developed materials to the ranking

- Compare overall performance with established materials
- Assess competitive potential ealry in development process

Adaption of framework to other cases and environments

- Expansion of holistic method to other types of construction