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Academic Entrepreneurship and Technical Considerations for the Commercialization of Biomaterial-Based Medical Devices

Review Article

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Abstract

Academic entrepreneurship, which refers to the university-based initiatives to encourage commercialization on campus and in the surrounding community, has evolved considerably in the recent years. Increasing number of stakeholders have been interested in academic entrepreneurship, and institutions have established higher number of strategies to encourage this development. Universities are organizations that play an important role in modern society by teaching, as well as research and development activities to produce scientific knowledge. Many institutions have recently taken important steps to create a "third purpose", by fostering connections within knowledge and users through promoting technology transfer, sometimes at the request of policymakers. Commercialization of knowledge produced in the academia, which includes patenting and licensing of findings, together with academic entrepreneurship, has gained a lot of attention from both academics and policymakers among the multiple pathways available for forging these linkages. Because it represents direct, demonstrable market acceptance for academic research results, commercialization is seen as a rising model for achieving academic influence. Many institutions have built specialized organizations, such as technology transfer offices (TTOs), scientific parks (Technopolis), and incubators, to aid commercialization as well as supporting internal policies and processes. The linkage between the universities and the industry have massively strengthened through academic entrepreneurship. There has been a significant impact on the regional and economic development due to the technological patents and spinoff companies emerged as a result of the research activities in universities. In this comprehensive review, the recent patent applications in the field of biomaterials in Turkey, Europe, and the United States of America were also covered, highlighting the number of patent applications of different biomaterial subgroups.

Keywords: Academic entrepreneurship; Patent; Licensing; Technology Transfer Office; Technopolis; Biomaterials; Commercialization.

1. INTRODUCTION

Starting a business by taking several risks, either to gain profit or to endure the losses is considered as entrepreneurship. The term entrepreneurship includes all processes of marketing, planning, development strategies. Moreover, the definition is constantly evolving in line with the technological developments and sophisticated research and development (R&D) activities. As a result of all of the cumulative activities in the field, entrepreneurship is becoming one of the most popular topics of today. It actually plays a vital role in global and national economic growth. Entrepreneurship will benefit the community just as it will profit the individuals. Entrepreneurship plays a major role in the social and economic development of societies, providing benefits such as creating new jobs and employment opportunities, developing new products and new ideas, as well as creating national income [1, 2].

Every person who starts a business is called an entrepreneur. Entrepreneurs create changes in the society by seeking ways to turn crises into opportunities. The term “academic entrepreneurship” is similar; but there are slight differences. In specific, academic entrepreneurship is the process of commercializing and transforming knowledge into business ideas and organizations. In simple words, this means making use of knowledge, research and development towards starting innovative ventures.

Academic entrepreneurship is the “third mission” of the higher education, and it strives to connect academia, the commercial sector and R&D together. This is also known as “intellectual enterprise”, where the universities collaborate with institutions and communities to create business ideas and ventures. Academic entrepreneurship has diverse principles compared to other entrepreneurship activities as it moves slow, studies the problem in detail, functions in constraints, and focuses on patterns. In universities, academic entrepreneurship has a significant role to play as it involves scientific research. This scientific research helps in generating revenue as their findings have commercial applications. Therefore, universities foster entrepreneurial activity and revenue generation. These are central to the academic entrepreneurship phenomenon [3].

The three fundamental concepts of academic entrepreneurship can be summarized as:

- It is based on knowledge and revolves around technological development.
- It is an income activity that arises from technology development.
- A specific behavior is adopted to alter the pattern of research.

There are many definitions of academic entrepreneurship, as a term, which covers the scientific publication of research results, as well as the profit out of these results. Both these outcomes can happen through a patenting process, which itself is a non-commercial activity [4]. In many countries, university licensing, patenting and starting a young companies (start-ups) began to become very common.

Academic entrepreneur is a scientist or a university professor, a PhD student or a post doctorate fellow who starts and sets up a company to justify and commercialize the results of the research done in the laboratory. The results of the research are used to set up a business and direct link is created between academia and industry. Usually, academic entrepreneurship occurs within an academic institution or by group of individuals who are generally research scholars and who acts independently. Thus, an academic entrepreneur is similar to a business entrepreneur who gives practicality to his or her idea - which is in the form of results of the research and builds a business based on it. Both the R&D work and production and marketing work is done.

There has been a significant increase in the commercialization activities of academic knowledge and other technology transfer movements since the implementation of the "Bayh–Dole Act" in 1980 in the USA. The Act allows colleges to get the Intellectual Property Rights (IPR) of inventions created by their staff on campus. Besides the USA, other countries including Canada, Australia and other European and Asian countries have seen an increase in university licensing, patenting, and start-up development since then [5]. These commercialization endeavors have been referred to as "academic entrepreneurship" that differs from other types of entrepreneurships in several ways. For example, since in these entrepreneurial ventures the academics devote their time and energy to the university, the university at least partially owns the intellectual property rights.

Academic entrepreneurship has evolved considerably since its first inception, specifically boosted by the launch of University Technology Transfer Offices (TTOs). There was a considerable emphasis on two essential characteristics of university technology transfer when these activities were originally started on campuses: patenting and licensing. The startup aspect received little attention because it would take focus away from the 'block-bluster' patent-licensing arrangements. Furthermore, because there were few entrepreneurship courses and programs on campus, people working in the research venture were unfamiliar with entrepreneurship and even remained not so connected to the entrepreneurial community. Additionally, academic entrepreneurship has just been introduced into the economic development missions of many universities [6].

This review article summarizes the basic concepts of academic entrepreneurship by specifically emphasizing its effects on the academia and on the industry, as well as the commercialization aspects of biomaterial-based products; mainly stemmed from the start-ups that fueled their development. Moreover, recent patents and commercialization activities within the academic entrepreneurship-based biomaterial development are also covered.

2. ACADEMIC ENTREPRENEURSHIP

Bayh-Dole Act

Bayh-Dole Act is a law, also known as Patent and Trademark Act Amendments. The act is a great help to promote the development of many start-ups and research organizations. This helps the universities, non-profit research institutes and small business enterprises to secure a patent. Through the act, these institutions can commercialize the inventions which was conducted within their organization. The act was a landmark development as it helped for the development of around 10k startup companies and around 200 drugs/vaccines and other medical products; with economical contribution in the level of $1.3 trillion to the U.S. economy since its implementation [7, 8]. The act provides rights for the university to retain its intellectual property (IP), which promotes the academic entrepreneurship. The act is, therefore, a gateway to promote academic entrepreneurship and has been a great success.

Progress of Academic Entrepreneurship

There are many ways by which academic entrepreneurship is being promoted by the universities. A popular way is to mandate entrepreneurship and connect the R&D of the faculty with creation of new patents. Research needs to be oriented towards IP rights. Another way is by offering grants for projects that address some technological or contextual problems that the local communities face, and thus create innovations that improve the lives of local communities. So, the process of academic entrepreneurship begins before a research project begins. Known as the incubation period of academic entrepreneurship, this period brings together like minded experts from different disciplines who share their ideas of opportunities and new collaborations that are feasible. Often in these cases, the university serves as the investor or as research makes significant progress, universities call on outside investors to participate in project presentations and updates. At this stage, when the product or idea is reaching completion, marketing becomes a very important aspect of the project.

Effect on Industry

Academia and industry are interconnected structures due to information exchange. This interconnectivity has further increased in recent years due to the increase in the frequency of academic entrepreneurship. Academic initiatives affect the industry in terms of finding more funding opportunities when in collaboration with the academic research, since the reliability to the research and potential outcomes increase. In addition, academics generally have less difficulties in allowance. Universities have increasingly begun to increase competition in trade. With the growing ambition among universities, the number of members engaged in academic entrepreneurship in universities has increased.

The main effects of academic entrepreneurship on the industry can be summarized as follows:

- Academic entrepreneurship has provided assistance to the industry as various unsolved industrial problems have found solutions through the research carried out in the academia.
- Academic entrepreneurship has increased the importance and scope of the R&D departments in the industrial organizations.
- Academic entrepreneurship has increased the scope of innovation and creativity in the industry.
- Through innovative ideas and application of more sophisticated production techniques, upgraded systems can be applied in the industry that reduces waste and increases the efficiency of production.
- With a higher level of academic information, one can develop the industrial processes through innovative products, protocols and work environments.

Effect on Academia

Along with academic entrepreneurship, the ongoing debate about expanding the mission of universities beyond education and research for economic and social development has further revealed the need for a view of corporate entrepreneurship in the university environment. Universities have taken on a different mission through the "change" initiated. With this mission, expectations from academics have also changed. In today's academy, it is expected not only to produce intellectual knowledge, but also to create added value in the economy by using this knowledge. Many academics actively involved within disciplines of science, engineering, life sciences and medicine and has entrepreneurship activities are likely to apply their knowledge to their startup's benefit, and these concepts are frequently classified as high-tech fields [9].

With the spread of academic entrepreneurship, some universities began to be called as "entrepreneurial universities". The main goal of entrepreneurial universities is to instill entrepreneurial spirit in students and researchers. This creates many tasks for universities, such as including entrepreneurship courses in their curriculum. In addition, an entrepreneurial university should have a wide interface, such as technology office license, and a technology transfer office. As this requirement affects universities economically, it is inevitable that positive returns will be received in education after these requirements are done.

The main effects on academia on entrepreneurship are as follows:

- Academic entrepreneurship has increased the scope for academia in terms of quality research as more people are willing to carry out research so that can be land up being an entrepreneur.
- Academic entrepreneurship has increased the scope for academic researchers' profession as now they have the option to enter into corporates rather being into academics.
- Through academic entrepreneurship, institutions create a connection between education and commerce for the development of society.
- To widen the information towards academic goals.
- To establish expertise knowledge through different platforms, so as to learn and grow.

Effect and Impact of Academic Entrepreneurship

The main importance of academic entrepreneurship is:

- It creates a significant shift in the circulation of academic information.

- It provides a platform for academic experts to share their knowledge and work with the mass population.
- It creates opportunities for academic institutions in finding ways to tackle uncertainties.
- It helps to design innovative ventures right from the source of research and knowledge.

The advantages and potential disadvantages of academic entrepreneurship are discussed below:

Advantages

Academic entrepreneurship is a good measure to test the practical applicability of an idea or concept and it lets the academic know if their concepts can withstand in the real world; a good theory needs to have the ability of being adaptive. So, practical application lets academics know if their concept and are feasible or if changes are needed.

Another advantage is that if the entrepreneur chooses to use their academic skills for market situations and develop a revenue model, then they are decently compensated for the same and can capitalize on their ideas. This economically contributes to their careers helping them to raise funds for future studies or any other need in terms of their academic projects and even otherwise in nonacademic field.

Academic entrepreneurship is also extremely important as it helps in educating the students about various entrepreneurial activities. Apart from it, it also emphasizes training the students and create awareness regarding the entrepreneurial activities. The main essence of academic entrepreneurship is the rise in the number of academic startups and hence better scope for the commercialization of the innovative idea. When there is a rise in entrepreneurial activity then it will result in contributing to the economy in a positive way.

Disadvantages

It needs to be highlighted that if academics devote their attention to suiting the market needs and in capitalizing an idea, they might come in conflict with certain ethical standards within their fields of study. Sometimes some amount of confidentiality needs to be maintained in academic study which is generally neglected in market models. Also, market needs might modify an academic concept or idea to make it more "sellable" while compromising on the ethical value.

The second negative impact could be that in case of entrepreneurship the market and the sales targets, revenue etc., the prime benchmarks of the potentiality of an idea or concept can become the sales rather than its scientific impact. This means that valued peer reviews which are held in much high esteem in academic field are neglected so the intellectual value of an idea translates into merely with the same value of the idea.

3. TECHNICAL CONSIDERATIONS IN THE COMMERCIALIZATION OF BIOMATERIAL-BASED MEDICAL DEVICES

Biomaterials are basically defined as the materials that interact with the human body or body fluids for a therapeutic or diagnostic purpose. Living cells or synthetic materials such as polymers, metals or ceramics etc. can be used to create these materials as long as they are convenient in terms of biocompatibility. From the production of biomaterials to their sale, there are various regulatory requirements that must be followed, with the primary role of preserving human health by assuring product safety, efficacy and quality. First step for technical consideration is understanding the characteristics of the biomaterial and it is critical because each material has its own set of strengths and weaknesses, thus, has its own set of regulations, standards, and testing techniques. Second, intended use because in some cases, the same device is regulated differently depending on the indication. Third, knowing which regulations apply in the region where the product will be sold, as regulations change by country. These understandings are crucial to a medical product's long-term success because if not properly addressed, regulatory rules can become challenges to commercialization but, on the other side, they can also be a great source of knowledge to help with the development process.

As previously stated, in the process of biomaterial commercializing there are many different technical requirements to be met and regulations which differs from country to country and material to material. Today, collaborative organizations such as the FDA (for the United States) and the EMA (for the European Union), or equals due to their aims, methodically create these guidelines. Before a product created may be put on the market, these institutions must approve it.

For the analysis of the regulatory requirements, biomaterials can be divided into two sub-headings. These are synthetic and biologically-derived biomaterials [10-13].

Regulations Related to Synthetic Biomaterials

Synthetic biomaterials are classed as ceramics, metals, synthetic polymers and their composites and are made utilizing a range of processing processes. There are two main regulatory pathways for commercializing these biomaterials: risk analysis and safety process, and efficacy process.

Risk Analysis and Safety: Since the goal of biomaterials is to diagnose, treat or cure a wide range of pathologies, the materials used in the product should not expose the patient to risk even though there is no such thing as zero risk. When a manufacturer chooses from the often-limited number of materials suitable for healthcare applications, the risk-to-benefit ratio must be taken into account in all cases. The initial step is to specify the risk classification and analysis, followed by biocompatibility tests, manufacturing process which is production, sterilization, packaging and quality to ensure safety.

Global Risk Classification and Analysis: Depending on the application, the risk classification terminology and different regulatory controls are required for biomaterials. These include the degree of surgical invasion or physical contact, the length of the service, the activity, and the energy sources or technologies employed. The risk classification differs from country to country.

Class II to IV and active implantable devices are the focus of nonclinical testing, which refers to in vitro or in vivo experiments in which test objects are evaluated prospectively in test systems under laboratory circumstances to determine their safety. Low-risk and noninvasive Class I or A medical devices, on the other hand, are rarely subjected to nonclinical testing. The classification of a device is usually the first step in determining the regulatory pathway and study requirements.

A rigorous procedure used throughout product development to establish what is required to show safety is known as risk analysis. One of the most often used methods is Failure Modes and Effects Analysis (FMEA). It is a strategy for systematically examining a process to determine where and how it could fail, as well as the relative impact of various failures, in order to determine which areas of the process require the most changes. The technical considerations that must be addressed in the context of safety can be identified using the FMEA framework. Most regulatory bodies believe that safety should be built into the development phase rather than the manufacturing process since it helps to minimize problems caused by changes that must be made prior to production. As previously said, FMEA is extremely beneficial at this stage because it not only ensures patient safety but also helps to avoid business implications [11, 13].

Regulatory Issues Related to Biologically-Derived Biomaterials

Natural biomaterials are commonly used to replace or restore the structure and function of injured tissues/organs because of their advantages such as biocompatibility, biodegradability, and remodeling. They can support cell adhesion, migration, proliferation, and differentiation effectively. Naturally generated biomaterials, when transplanted into a damaged area, can stimulate the adhesion and migration of cells from the surrounding environment, resulting in extracellular matrix synthesis and tissue repair. Some commercial products were made from naturally derived biomaterials including small intestinal submucosa (SIS), Matrigel®, Alloderm®, etc.

Protein-based biomaterials (such as collagen, gelatin, and silk), polysaccharide-based biomaterials (such as cellulose, chitin/chitosan), and decellularized tissue-derived biomaterials are all examples of naturally generated biomaterials (decellularized heart valves, blood vessels, liver, etc). Biomaterials made of proteins and polysaccharides can be made in two methods. Solvents or enzymes dissolve protein and polysaccharide from living organisms. The fibrils are then precipitated and reconstituted. The removal of additional constituents of live creatures using solvents or enzymes is the second method for preparing protein and polysaccharide. All cells from native tissues/organs are removed to make decellularized biomaterials. To create a successful decellularization strategy, physical, chemical, and enzymatic techniques are utilized [14].

Biocompatibility Tests

By definition, biocompatibility is a measurement of a device's compatibility with a biological system. The goal of biocompatibility testing is to evaluate if a technology is fit for human usage and if it can cause any possibly hazardous physiological consequences. All biocompatibility testing for biomaterials takes place before any clinical testing. The International Organization for Standardization (ISO) sets the main regulatory standards for nonclinical biocompatibility and medical device testing (ISO). Some countries, on the other hand, utilize parallel national and regional standards such as FMEA.

Confirmation of the device's suitability for its intended purpose is at the basis of the ISO Standard. When learning about biocompatibility standards, the ISO Standard 10993, Biological Evaluation of Medical Devices, is a good place to start, and using it as a guide will make selecting the right test much easier. These tests can include everything from skin irritation and sensitization assays to hemocompatibility and implantation tests thus it is essential to choose the right ones [10, 11, 13].

Manufacturing

Manufacturing is a long, complex process that involves careful coordination and control at every stage which is production, packing, sterilization and quality control and assurance. This control process is carried out in accordance with a procedure known as Good Manufacturing Practice (GMP) as a sub-branch of Quality System Regulations (QSRs).

GMP is a concept that ensures that products are produced and subsequently controlled according to quality standards. The goal is to lower the risks associated with the manufacturing process. It includes all aspects of production starting from raw materials to related facilities and equipment, and to training and behavior of personnel.

One of the technical concerns for manufacturing processes is sterilization. The purpose of sterilization is to render non-sterile medical devices sterile by inactivating microbial contamination. Sterilization can be accomplished through a variety of product and packaging sterilization methods. The sterilization techniques as either traditional (such as ethylene oxide or radiation) or non-traditional (such as hydrogen peroxide). The method and dose are determined by the product's structure and properties. The ability of biomaterials to be sterilized is critical for commercialization because non-traditional methods require more work to demonstrate their effectiveness and encounter regulatory oversight.

Another critical technical step in the biomaterial manufacturing is packaging. The package protects the device from external influences such as microorganisms during handling and shipping until the product is ready to use. General safety and performance requirements (GSPR), specifies the packaging requirements of medical devices. Because of packaging includes product identification, labeling, and user interaction, it must be properly prepared.

Finally, to ensure that devices manufactured and marketed are safe and effective for the intended user, manufacturers use a quality system known as a Quality Management System (QMS) that is compatible with regulatory criteria. A quality management system includes both quality assurance and quality control. Quality assurance ensures that a medical device's manufacturing process is free of faults. It occurs throughout the medical device manufacturing process, and their personnel ensures that it complies with the related regulations. On the other side, quality control finds defects in products after they have been manufactured but before they are distributed. Quality control checks individual products or batches of products to determine whether it satisfies specified product specifications. The goal is to identify defective products before they reach the end consumer [11].

Efficacy

The biomaterial's ability to achieve what it claims must be demonstrated. The FDA uses a number of tests such as animal testing to assess how effective and long-lasting products are and to establish the appropriate regulations. Test methods are promulgated by ISO or varieties and they must prove the efficacy of the product [11].

4. ROLE AND IMPORTANCE OF PATENTS FOR COMMERCIALIZATION OF BIOMATERIALS-BASED PRODUCTS

What is a Patent and How to Apply for It?

A patent is a document that states that the inventor has the right to prevent others from producing, using, selling, or importing the product which is subject to the invention, for a certain period of time.
Firstly, there are different kinds of industrial and intellectual property protections such as patent, trademark and copyright. It is important to know the differences between these protection types, since the inventor has to clearly determine the type of the property protection. In other words, the question: “Do I really need a patent?”, has to be asked by the inventor(s).

As a next step, a patent search is needed before applying for a patent, because a patent application cannot be filed if it has already been publicly disclosed. The search for foreign patents is also advisable. Depending on the invention, the type and route of the application will also be different. For instance, the European patent office (EPO) accepts applications done to the European Patent Convention (EPC) or the Patent Cooperation Treaty (PCT) [15]. However, there is no need to apply to the European patent office, if the inventors are seeking protection in only a few countries. In that case, an application for a national patent directly to each of the national offices (eg. Turkish or US Patent and Trademark Office - USPTO) will be proper. Patent applications are mainly composed of a request for grant, a description of the invention, claims, drawings (if any), and lastly an abstract. It is advisable to fill the applications in the official languages determined by the patent offices, otherwise an extra translation has to be submitted. Once the application is being filed, nothing new can be added to the application. With all necessary information and documentation and completed filing (eg. an indication that a specific patent is sought, details identifying the applicant, description of the invention etc.), the application may be accorded a filing date.
Within the process of examination, further determination whether the application meets the requirements of the patent office and whether it can be granted, is being investigated and a response (search report) about the claimed invention is sent to the applicant(s). The report may also include the appropriate fees (changing with the national laws) that must be paid previously within a time limit. During this process, a designated attorney who communicates with the office may represent the inventors. After the patent is being granted, maintenance fees have to be paid in order to maintain the patent, otherwise the patent will expire [16].

Another important subject for patent search is to know the classification system of the intended patent office. For example, Turkish Patent and Trademark Office uses International Patent Classification (IPC), which provides a hierarchical system using symbols instead of different languages. Cooperative Patent Classification (CPC) originates with the cooperation of USPTO and EPO to form a system that harmonizes the existing classification systems.

After the general search is completed and the classification system is understood, a detailed patent search using the patent office archives needs to be done. In the following Section, recent patent applications in "biomaterials" field were covered via Turkish Patent and Trademark Office (Türk Patent Enstitüsü; TPE), EPO, and USPTO.

Recent Patent Applications in Biomaterials Field

The results of the search for patent applications in biomaterials field between 2019 – 2021 are being graphically represented in this Section [17, 18]. During the investigation, the patents were grouped according to the type of biomaterial described in the patent. Three different graphical representations were created in order to examine the similarities and/or differences among the patent offices which were taken under consideration (TPE, EPO and USPTO). In general, when the overall patent application numbers are compared, it is seen that the numbers are very similar for applications to USPTO (409) and EPO (406) during these years. In other words, there is an equal request to both patent offices. On the other hand, the number of applications in TPE is very low (11), compared to both EPO and USPTO.

It can be observed in **Figure 1** that applications to USPTO is majorly filed in the field of "implantable biomaterials". The category following it is the "polymeric biomaterials", and "composite materials" is the next one. On the other hand, it was observed that a significantly lower number of patent applications were filed in the fields of biodegradable, biomimetic, or injectable biomaterials to USPTO between 2019-2021.

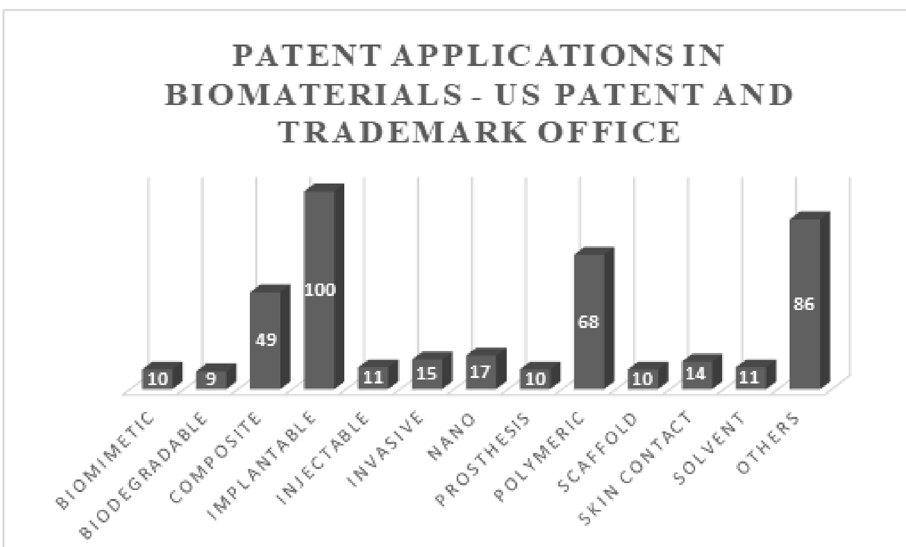

Figure 1. Graphical representation of the patent applications filed to USPTO between 2019-2021.

The trend in the applications to EPO was similar during this time period (**Figure 2**); composite, polymeric and implantable biomaterials are also the leading sub-groups [19]. Furthermore, applications for especially "coating materials" are seen in the EPO database, which was not grouped for USPTO. In other words, the range of biomaterial types are expanded in EPO. However, the main in-demand groups or types of biomaterials in USPTO as well as in EPO are equal.

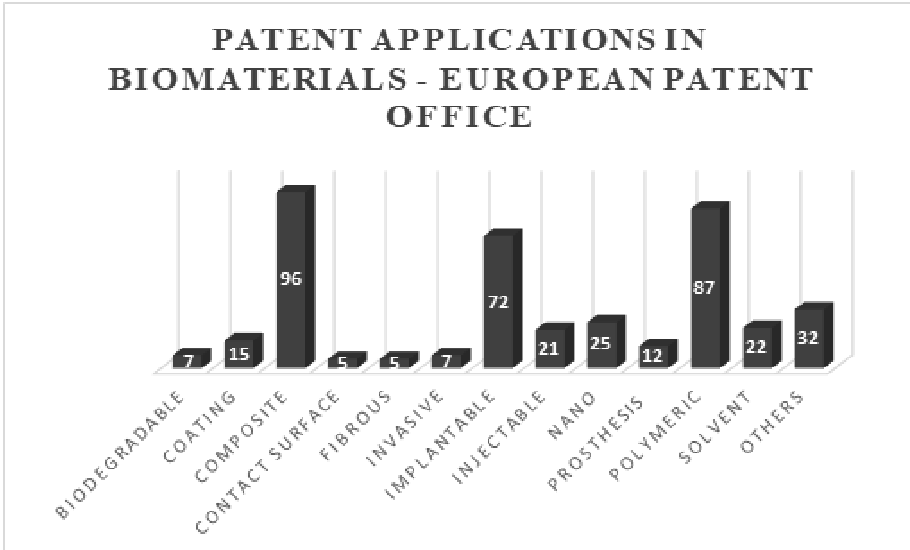

Figure 2. Graphical representation of the patent applications appealed to the EPO between 2019-2021.

The number of applications in Turkey are very low compared to the other two offices as previously described. The leading group for applications to TPE between 2019-2021 is “nanomaterials” that are followed by “metallic materials” (**Figure 3**). An important notice is that, there was no reported group in particular for metallic materials neither in USPTO nor in EPO.

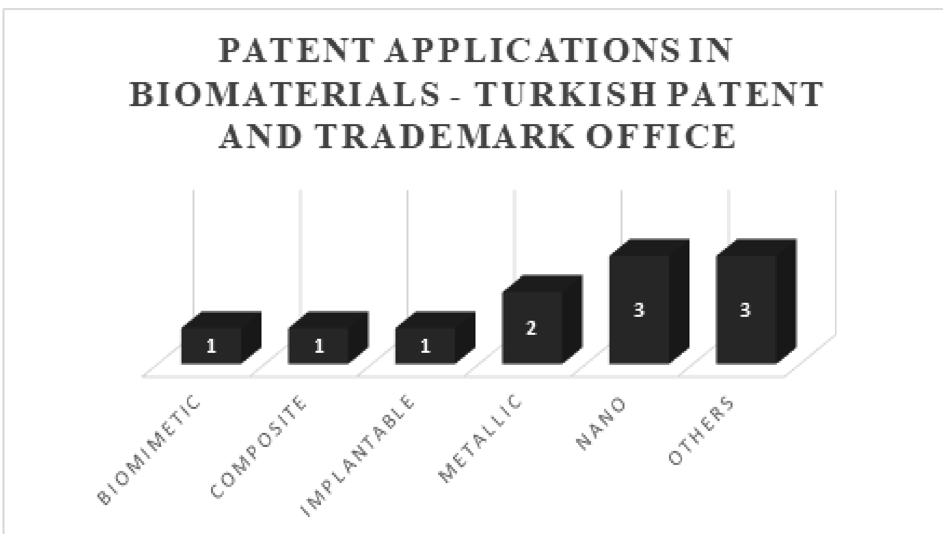

Figure 3. Graphical representation of the patent applications appealed to the Turkish Patent and Trademark Office between 2019-2021.

Figure 4 and **Figure 5** are representing the applicants (countries) that filed an application to USPTO and EPO, respectively. In both the USPTO and the EPO, the United States is the country that made the most applications and; therefore, the most inventions in biomaterials. Following the US, Japan and Korea are the second and third countries that has the highest number of applications. Additionally, the USPTO, as well as EPO, received one application from Turkey in the area of biomimetic biomaterials between 2019-2021.

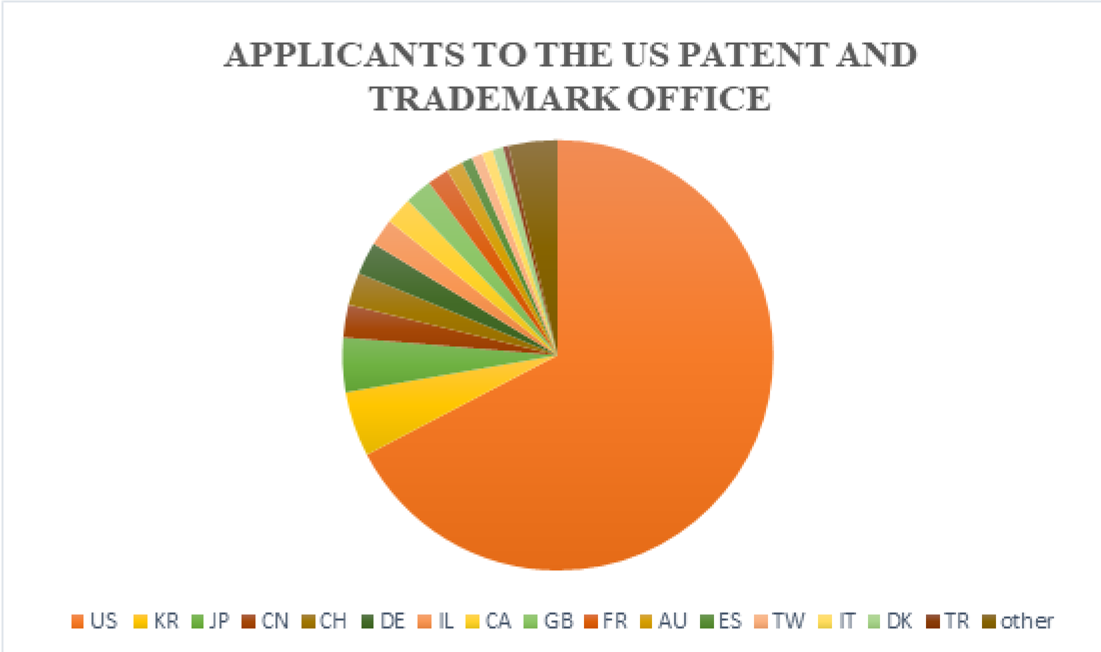

Figure 4. Graphical representation of the applicants (countries) to the USPTO between 2019-2021.

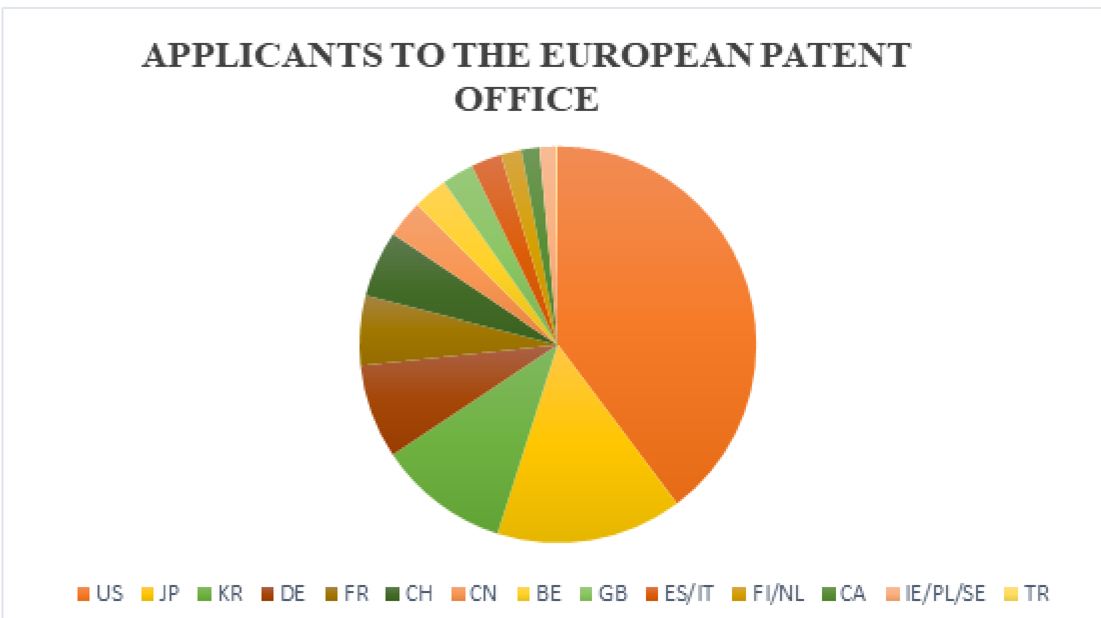

Figure 5. Graphical representation of the applicants (countries) to the EPO between 2019-2021.

5. CONCLUSION AND FUTURE PROSPECTS

Academic entrepreneurship, depending on the development of knowledge-based economies and the changing role of universities, is the sum of commercial activities of academics in their field of new essential technologies, new products or processes, and services that also contribute to development. In this review, academic entrepreneurship was discussed in a general framework and evaluated both for its processes and pros/cons. One of the biggest influences of academic entrepreneurship on the industry is the number of companies and the variety of products.

The interaction of human beings with biomaterials starts from prehistoric times. Biomaterials, which are used in almost all medical fields today, will appear in different forms in different fields in the future.

For this reason, biomaterials must be produced, sold and used in surgeries with care and within the framework of certain rules. Considering its importance for humanity, biomaterials should be subjected to various tests and inspections. Commercialization of biomaterials is a lengthy and difficult process involving multiple stakeholders and numerous issues beyond the technical characterization of the biomaterial, and in this process, the assistance of experts in this field should be sought, and the production and sale of the biomaterial should be carried out in accordance with the guidelines.

Patents are among the first cornerstones in the road to academic entrepreneurship. In this review, we have done a comprehensive patent search in biomaterials field between 2019-2021; for the patents filed to USPTO, EPO and TPE. Our findings were used to prepare number-based charts for USPTO, EPO, and TPE, as well as country-based charts. Based on these charts the following conclusions can be drawn:

- There is an intense recent interest in specific biomaterial types including implantable, polymeric and composite biomaterials.
- There are neglected areas in the field of biomaterials that might need improvement in the future, such as nano-, injectable-, biodegradable-biomaterials.
- The countries that file the most applications are US, Japan and Korea which implied the recent sources of inventions in the field of biomaterials.

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Removal of Radioactive Gas by Zeolite Filter from Nuclear Power Plants

Research Article

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Abstract

During the normal operation of nuclear power plants, some radioactive wastes are produced in the form of particles or aerosol gas in the reactor building. Particulate radioactive aerosols can be produced in a wide variety of particle sizes, possibly in combination with non-radioactive aerosols. Emission of corrosion products and fission products that are activated by the effect of nuclear rays generate aerosols from two sources. These; are created by the adsorption of gases generated by radioactive decay and volatile radionuclides formed during the fission process on the present suspended material. The most important volatile radionuclides that form the gaseous radioactive waste produced during the normal operation of nuclear power plants are halogens, noble gases, tritium, and carbon-14. The composition and amount of radioactivity present in the various airborne waste streams depend largely on the reactor type and release path. All gaseous waste from nuclear power plants must be treated before discharging into the atmosphere. In this paper, radioactive radon gas was used to represent the radioactive gases generated from nuclear power plants and natural zeolite was used as adsorbent material for radon removal. A series of experiments were conducted to measure the performance of the filter made in the zeolite. First of all, an approximate particle distribution size in the range of 1 to 3 mm was obtained by grinding natural zeolite. The ground material was then compressed in cylindrical adsorbent moulds of 35 mm diameter and 10 mm height. After the moulds were filled with the material, they were dried by heating to 110 ° C for 24 hours. At the end of the heat treatment, the adsorbent beds were cooled and connected to the test apparatus. RAD7 radon test device was used in the experiments. The RAD7 is a portable instrument that uses a solid-state alpha detector to measure radon gas concentrations in the range of 4.0-750,000 Bq / m3. The sampler of the RAD7 device works by drawing an air sample from an inlet filter into a 0.7 L sample cell covered with an electrical conductor. At the centre of the hemisphere, the cell is a planar silicon detector implanted with an ion to measure radioactivity. As result of the experiments, it shows that the zeolite filter absorbs 85% radioactive radon gas and can be used as an air filter in nuclear power plants.

Keywords: Radioactive, radon, gaseous, zeolite, filter.

Özet

Nükleer santrallerin normal çalışması sırasında, reaktör binasında partikül veya aerosol gazı şeklinde bazı radyoaktif atıklar üretilir. Parçacık radyoaktif aerosoller, çok çeşitli parçacık boyutlarında, muhtemelen radyoaktif olmayan aerosollerle kombinasyon halinde üretilebilir. Nükleer ışınların etkisiyle harekete geçen korozyon ürünleri ve fisyon ürünlerinin emisyonu iki kaynaktan aerosol üretir. Bunlar; radyoaktif bozunma tarafından üretilen gazların ve fisyon işlemi sırasında oluşan uçucu radyonüklidlerin mevcut asılı malzeme üzerinde adsorpsiyonu ile oluşmaktadır. Nükleer santrallerin normal çalışması sırasında üretilen gaz halindeki radyoaktif atıkları oluşturan en önemli uçucu radyonüklitler halojenler, soy gazlar, trityum ve karbon-14'tür. Havadaki çeşitli atık akışlarında bulunan radyoaktivite bileşimi ve miktarı, büyük ölçüde reaktör tipine ve salınım yoluna bağlıdır. Nükleer santrallerden çıkan tüm gazlı atıklar atmosfere deşarj edilmeden önce arıtılmalıdır. Bu yazıda, nükleer santrallerden üretilen radyoaktif gazları temsil etmek için radyoaktif radon gazı kullanılmış ve radon giderimi için adsorban malzeme olarak doğal zeolit kullanılmıştır. Zeolit içinde yapılan filtrenin performansını ölçmek için bir dizi deney yapılmıştır. Öncelikle, doğal zeolitin öğütülmesiyle 1 ila 3 mm aralığında yaklaşık bir parçacık dağılım boyutu elde edildi. Öğütülmüş malzeme daha sonra 35 mm çapında ve 10 mm yüksekliğinde silindirik adsorban kalıplarda sıkıştırılmıştır. Kalıplar malzeme ile doldurulduktan sonra 110 ° C'de 24 saat ısıtılarak kurutuldu. Isıl işlemin sonunda adsorban yatakları soğutulmuş ve test aparatına bağlanmıştır. Deneylerde RAD7 radon test cihazı kullanılmıştır. RAD7 cihazı, 4.0-750.000 Bq / m3 aralığındaki radon gazı konsantrasyonlarını ölçmek için katı hal alfa dedektörü kullanan taşınabilir bir cihazdır. RAD7 cihazının örnekleyicisi, bir giriş filtresinden bir hava örneğini bir elektrik iletkeni ile kaplı 0,7 L'lik bir örnek hücreye çekerek çalışır. Yarım kürenin merkezinde, hücre, radyoaktiviteyi ölçmek için bir iyon implante edilmiş düzlemsel bir silikon detektördür. Deneyler sonucunda zeolit filtrenin % 85 oranında radyoaktif radon gazını tutabildiği ve nükleer santrallerde hava filtresi olarak kullanılabileceğini göstermektedir.

Anahtar Kelimeler: Radyoaktif, radon, gaz, zeolit, filtre.

1. INTRODUCTION

Fission and activation gases are also produced during the normal operation of nuclear power reactors. Radioactive gases are transported to various parts of the building where the facility is located as a result of their leakage in the reactor system. This is because the gases formed during the reaction are completely dissolved in the reactor cooler. As a result, if a suitable filter is not used, fission gases and radioactive particles spread around the facility. By integrating suitable filters into the plant ventilation system, these gases are kept in the filter environment and not spread to the atmosphere. In nuclear power reactors, radioactive gases are trapped with filters in order to minimize the radioactivity released into the environment. In addition, radionuclides in the form of particles can also be transported in the air in nuclear power reactors. The emission points and size of radioactive gases and airborne particles depend on the reactor type (PWR / BWR) and plant design. Typical gaseous and airborne particle source terms are defined in Table 1. The main sources of gaseous waste generation are presented in Table 2.

Radioactive gas waste systems from nuclear power reactors are designed to keep the fission and activation gases at extremely low levels for radioactive decay before they are released. Containment methods include storage in pressurized tanks, long delay lines, and holding by absorption in charcoal beds. The gas retention system, consisting of filters to keep radioactive gases free from the environment, is integrated with radiation monitors that are capable of monitoring emissions and also detect leaks, spikes, or other unintentional releases.

Table 1. PWR Gaseous Source Terms Prior to Treatment.

Gaseous Radionuclide	Ci/year
Kr-85m	2.7
Kr-85	2.6
Kr-87	1.1
Kr-88	3.3
Xe-131m	6.5×10^3
Xe-133m	1.1×10^2
Xe-133	7.7×10^3
Xe-135m	3.0
Xe-135	2.8×10^2
Xe-137	<1
Xe-138	4.0
	Total: 1.7×10^4

The main gaseous fission products released in nuclear power reactors consist of various noble gases such as xenon (Xe) and krypton (Kr). Many fission products are produced during the nuclear fission process in reactors. Radioactive Gaseous fission products are released into the reactor cooling system due to defects in the fuel coating and transport through the fuel coating. Major emitted noble gases include (Kr, Xe) and radioiodine. Radioiodine can exist in a variety of chemical forms such as I2, IO3, HOI, and CH3I.

Activation products as well as gaseous fission products are released as a result of the nuclear fission process. Major released activation gases include nitrogen, oxygen, argon, and tritium. A large number of particles are also activated in the reactor environment with these radioactive gases. These particles include normal radionuclides found in both solid waste and liquid waste streams. A list of specific activation products that generally occur in PWRs is presented in Table 2.

Table 2. PWR Radioactive Particulate Release.

Radionuclide Particulates	Total Release Rate Ci/year
Cr-51	9.7×10^{-5}
Mn-54	5.8×10^{-5}
Co-57	8.2×10^{-6}
Co-58	4.1×10^{-4}
Co-60	5.9×10^{-5}
Fe-59	2.7×10^{-5}
Sr-89	1.6×10^{-4}
Sr-90	6.3×10^{-5}
Zb-95	9.1×10^{-6}
Nb-95	5.0×10^{-5}
Ru-105	1.7×10^{-5}
Ru-106	7.8×10^{-7}
Sb-125	1.7×10^{-6}
Cs-134	4.8×10^{-5}
Cs-136	3.3×10^{-5}
Cs-137	1.1×10^{-4}
Cs-138	2.9×10^{-6}
Ce-144	1.3×10^{-5}
Total:	1.2×10^{-3}

Since much more dangerous emissions are taken into account in nuclear accidents, radon gas emission is not usually included in this type of scenarios. But in some nuclear reactors, radium is used to provide alpha particles that can interact with beryllium to produce neutrons through the reaction and by this way radon gas is emitted. In scope of the nuclear decay chain, radon gas is the decay product of radium, and radium is the decay product of uranium. Since radon gas is the main decay product of radium, radon gas is one of the radioactive gases in a nuclear reactor.

PWRs have a relatively small volume of gas (15 cfm) enabling batch processing; Whereas, BWRs have high gas volumes (250 cfm), which necessitates a continuous processing system was defined by Moghissi, Godbee, and Hobart (1986, pp.2-3). Gaseous radioactive wastes are managed in three ways; a) Particle filtration, b) Gas adsorption, and c) Decay in holding tanks. Various filtering units have been designed to remove both gaseous radioactive waste and airborne particles. Commonly used systems include High-Efficiency Particulate Air Filters, HEPA filters, and coal adsorption. These systems include integrated holding tanks for degradation and final release.

2. METHODS AND MATERIALS

In this research, zeolite-based mineral composite filter was prepared and experiments were made to remove radioactive gaseous waste. Zeolite filters are prepared in 10 mm thickness and 45 mm diameter. Radon gas is used to represent radioactive gases. Radon gas retention performance of the mineral-based composite radon filters were determined. Laboratory tests were performed to determine effects of the additive ratio on the filter performance. Composite zeolite filter samples were prepared for this research (Figure 1).

Figure 1. Zeolite Filter Radon Test Device RAD7.

The trend in the applications to EPO was similar during this time period (**Figure 2**); composite, polymeric and implantable biomaterials are also the leading sub-groups [19]. Furthermore, applications for especially "coating materials" are seen in the EPO database, which was not grouped for USPTO. In other words, the range of biomaterial types are expanded in EPO. However, the main in-demand groups or types of biomaterials in USPTO as well as in EPO are equal.

Radon is a naturally occurring radioactive noble gas. It is part of the natural decay series of uranium (U) and thorium (Th) found in all soils and rocks to a varying concentration. There are three radioisotopes of radon naturally present in the environment: Radon-222 from the uranium-238 decay series, radon-220 from thorium-232 decay series and radon-219 from uranium-235 decay series. Radon-219 is of low radiological significance because of its short half-life of 4 seconds and uranium-235 represents a small percentage (0.3%) of the activity of naturally occurring uranium. Inhalation of indoor radon (222Rn) and thoron (220Rn) decay products is the most important source of exposure to ionizing radiation for the human respiratory tract suggested by Lubin et.al (1997, 126-134), Chau et al (1997, 69-74) and Yuan et al (2019, 204-205). In this study, the radon measuring device (Rad7) and integrated into the radon accumulation cell were used in the experiment system (Fig.1). CAPTURE software was used to evaluate the measured values. The regular gas flow was maintained via one-way gas valves to the radon measuring device (RAD7). The gas drying column was added to the test system as an intermediate stage in order to prevent the measurement system of the device from being affected by humidity. One-way valves are also used to prevent radon gas recirculation. The test system is integrated into the radon meter and the results are transferred to the computer via CAPTURE (Figure 2). In the beginning, unfiltered radon gas test measurements were taken in the sniffing mode and unfiltered radon gas activity values were determined. After the initial values were determined, the zeolite composite filter prepared for this study was used for performance measurements.

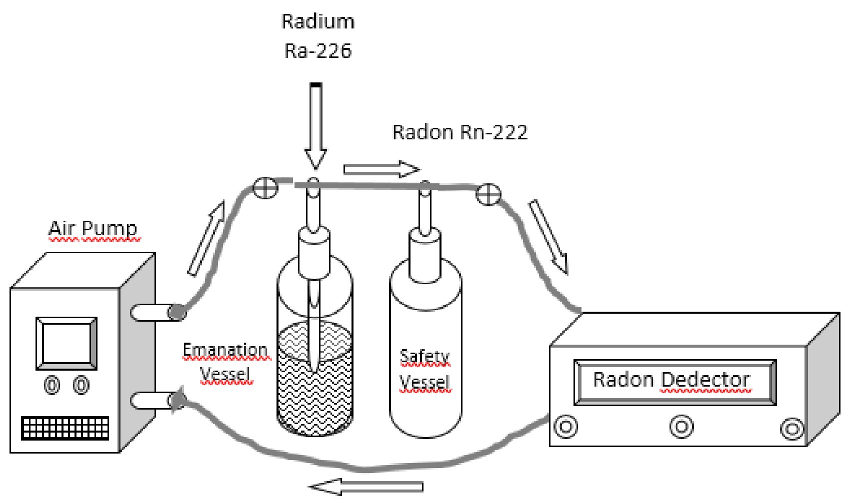

Figure 2. Radon Measurement System.

3. RESULTS

Zeolite filter tests were performed when the radon accumulation in the radon deposition chamber reached equilibrium. Initially, the reference material prepared only as binder material was tested as reference material. Then, each filter sample was placed in the filtration system and their adsorption capacities were determined. Comparison of additive amounts in terms of radon gas filtering and determination of filtering performance of composites is determined and results were presented in Figure 3.

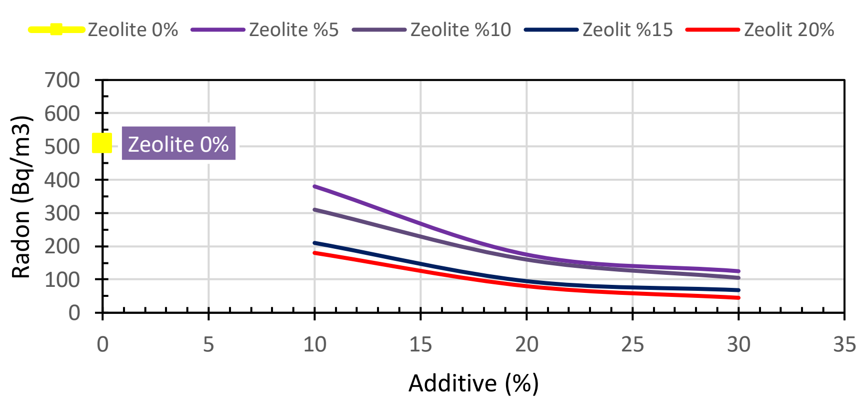

Figure 3. Filter Performance Test Results.

4. RESULTS

The performance tests of zeolite-added composite filters for removing radioactive gaseous wastes were successfully performed and their values were recorded. It was determined that the zeolite filters can hold 70% radioactive radon gas. In the case of comparison of test materials, the best performance was recorded for the 20% zeolite doped filter composite sample.

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A Vikor-Based Approach for Detergent Selection Problem From Sustainability Perspective

Research Article

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Abstract

The sustainability concept is getting more important due to the limited world carrying capacity and natural resources with increasing population around the world. As one of the Fast-Moving Consumer Goods, home cleaning has different impacts on both environment and health. In this context, using detergents reveal a research area because, they consist many ingredients that are worth to consider for sustainability and innovation. In daily life, detergents are consumed almost in every type of household activity; therefore, there is an increasing amount of detergent consumption. Even type of consumed detergent differs in terms of different regions, the most consumed type is defined as powder detergents according to European statistics. Such real-life cases complicate the decision-making process even more difficult because, they combine both qualitative and quantitative issues. In such cases, multi-criteria decision-making methods deal with uncertainties exist and contradicted criteria. Thus, the aim of the application is to detect the most appropriate detergent according to the sustainability dimensions by Vikor Method. First of all, five most purchased powder detergents were determined from top FMCG companies' annual reports and some related articles in literature. Secondly, algorithm of the Vikor Method was coded on MATLAB R2018a software and then, gathered data was integrated to evaluate the identified powder detergent options under sustainability metrics. As a result of this study, the most effective criteria are active ingredient and foam height from customer perspective without considering market share and retail price per net weight. Companies should focus on reducing negative effects of active ingredients while satisfying customer expectations and this ensures the preferability of a powder detergent from sustainability perspective.

Keywords: Detergents, Multi-criteria Decision Making, Sustainability, Vikor Method.

Özet

Dünya genelinde artan nüfus ile sürdürülebilirlik kavramı, Dünya'nın sınırlı taşıma kapasitesi ve doğal kaynak kapasitesine bağlı olarak git gide önem kazanmaktadır. Hızlı tüketim mallarından biri olan ev temizliği ürünlerinin hem çevre hem de sağlık üzerinde farklı etkileri vardır. Bu bağlamda, sürdürülebilirlik ve inovasyon için dikkate alınmaya değer birçok bileşen içeren deterjan kullanımı bir araştırma alanını ortaya çıkarmaktadır. Gündelik hayatta deterjanlar hemen hemen her türlü ev aktivitesinde tüketilmektedir. Bu nedenle, her geçen gün daha da artan miktarda deterjan tüketimi söz konusudur. Her ne kadar farklı bölgelere göre tüketilen deterjan türü farklılık gösterse de Avrupa istatistiklerine göre en çok tüketilen türün toz deterjanlar olduğu saptanmıştır. Hem nitel hem de nicel konuları birleştiren bu tür gerçek yaşam vakaları karar verme sürecini daha da zorlaştırmaktadır. Bu gibi durumlarda, belirsizlikler ve birbiriyle çelişen kriterler, çok kriterli karar verme yöntemleri ile değerlendirilmektedir. Tüm bu nedenlerle, bu uygulamanın amacı Vikor Metodu ile sürdürülebilirlik boyutlarına göre en uygun deterjan alternatifini tespit etmektir. İlk olarak, en çok satın alınan beş toz deterjan, en iyi FMCG şirketlerinin yıllık raporlarından ve literatürdeki bazı ilgili makalelerden belirlenmiştir. İkinci adımda, Vikor Metodu algoritması MATLAB R2018a yazılımına kodlanmış ve daha sonra, belirlenen toz deterjan seçeneklerini sürdürülebilirlik ölçütleri altında değerlendirmek için toplanan veriler MATLAB koduna entegre edilmiştir. Bu çalışma sonucunda, pazar payı ve net ağırlık başına perakende fiyatı dikkate alınmaksızın, müşteri açısından en etkili kriterlerin aktif bileşenler ve köpük yüksekliği olduğu saptanmıştır. Firmalar, müşteri beklentilerini karşılarken aktif bileşenlerin olumsuz etkilerini azaltmaya odaklanmalıdırlar. Bu sayede, sürdürülebilirlik açısından ürettikleri toz deterjanın tercih edilebilirliğini sağlamış olacaklardır.

Anahtar Kelimeler: Çok Kriterli Karar Verme, Deterjanlar, Sürdürülebilirlik, Vikor Metodu.

1. INTRODUCTION

Sustainability is a concept of integrating environment, economy and social areas in a way that can live together (Appleton, 2006, p. 3–18). By growing number of populations around the world, sustainability concept is getting more importance because of limited world carrying capacity and natural resources. In this case, governments have been started to make regulations about sustainable development and take actions in environmental, operational, financial and managerial processes within the country. There are some major areas which have to principally consider due to their negative effects especially on environment. As one of the Fast-Moving Consumer Goods sector area which is home cleaning has different impacts on both environment and health. In this context, using detergents reveal a research area because, they consist many ingredients that are worth to consider for sustainability and innovation (Hauthal, 2008, p. 30–42). The effects of each ingredient must be measured and consumers should prefer the least damaging product type. This decision problem needs a method which takes into account defined criteria and weight of each one. In the literature, the majority of multi-criteria decision-making problems tend to either discrete selection or customization of mathematical programming problems; however, an integrated multi-criteria decision analysis is sensitive to include both (Belton & Stewart, 2002). Multi-criteria decision-making involves identifying the optimal alternative between multiple, conflicting and interactive criteria (Yücenur, 2017, p. 779). This method, introduced by Opricovic & Tzeng (2007), focuses on sorting and selecting a number of alternatives and identifies conciliatory solutions that help the decision-maker reach the target for a problem with conflicting criteria. Multi-criteria decision-making methods are applied in many areas. Methods that use many qualitative and quantitative data are used in calculations which take into account different performance criteria and weights can be summarized such as TOPSIS, ELECTRE, AHP, ANP, DEMATEL etc. (Eleren & Karagül, 2008, p. 1–14). In literature, Lee et al. (2009) was applied to the Vikor Method to prioritize land use restriction strategies in the Tseng-Wen reservoir basin. Sayadi et al. (2009) was used the extended Vikor Method to solve decision making problems with intermittent numbers. Chatterjee et al. (2009) proposed the Vikor and Electre methods for material selection. Opricovic & Tzeng (2007) compared four multi-criteria decision-making methods: Topsis, Promethee, Electre and Vikor and found the Vikor Method as the best evaluation method.

2. PROBLEM DEFINITION AND OBJECTIVES

In daily life, detergents are consumed almost in every type of household activity; therefore, there is an increasing amount of detergent consumption. Even type of consumed detergent differs in terms of different regions, the most consumed type is defined as powder detergents according to European statistics (European Ecolabel Commission, 2011, p. 1–39). Such real-life cases complicate the decision-making process even more difficult because, they combine both qualitative and quantitative issues. In such cases, multi-criteria decision-making methods are solved uncertainties exist and contradicted criteria with each other. Multi-criteria decision-making methods are used to support the decision-making process and generally to select one or more alternatives from a set of alternatives with different characteristics according to conflicting criteria or to rank these alternatives from the best to the worst according to their performance (Deng, Yeh & Willis, 2000, p. 963–973). In addition, unlike other decision-making methods, multi-criteria decision-making methods can be applied not only for quantitative but also for qualitative criteria. Furthermore, different results can be obtained even when one of these methods is applied to the same problem with the same assumptions and the same decision makers (Zanakis, Solomon, Wishart & Dublish, 1998, p. 507–529). However, complicated cases cannot be manually solved to avoid time consumption and calculation mistakes. Therefore, decision makers need to design the problem by using a tool which supplies a flexible solution process and quick response. In this study, MATLAB software was selected due to its features to give a useful answer decision makers needs (Mokhtarian, Sadi-Nezhad & Makui, 2014, p. 213–233). For all of the mentioned reasons, the aim of this study is to demonstrate how Vikor Method is applied on the evaluation of powder detergent alternatives based on sustainability criteria via using a software. In this sense, this study presents a realistic problem that can be encountered in daily life.

3. METHODOLOGY

The Vikor Method is a method of combining functions that represents the closest solution to the ideal solution (Opricovic & Tzeng, 2007, p. 514–529). For the majority, it determines a compromise solution that is close to ideal, providing maximum group benefit and minimum individual remorse. The alternatives are evaluated according to each criterion and the order of reconciliation is achieved by comparing the ideal solution proximity measure. There is a linear relationship between benefit and each criteria function, and the decision maker's preferences are expressed by weights. With this method, it is possible to normalize the criteria values having different solution values and eliminate the difference arising from the unit values of the criteria and to create a ranking index (Opricovic & Tzeng, 2007, p. 514–529).

In the Vikor Method, the reconciliation value is calculated using the L_p measure in Formula 1, which is used in compromise programming. This method performs linear optimization and calculates the ideal solution as a ratio.

$$Lpi = \left\{ \sum_{j=1}^{n} \left[\frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right]^p \right\}^{\frac{1}{p}} \tag{1}$$

$$1 \le p \le \infty; \quad i = 1,2,\ldots,m$$

At initial step of the Vikor Method, Formula 2 and 3 give the best f_i^* (max) and worst f_i^-(min) values for each criterion. However, it should be noted that; if a criterion would be minimized, the formulas are replaced and i shows comparison criteria and j shows the alternatives.

$$f_i^* = max_j f_{ij} \tag{2}$$

$$f_i^- = min_j f_{ij} \tag{3}$$

As the next step, the average group value (S_j) and the worst group value (R_j) were calculated by using Formula 4 and 5. w_i values indicate the assigned weight of each criteria.

$$S_j = \sum_{i=1}^{n} \frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i)} \tag{4}$$

$$R_j = max \left[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i)} \right] \tag{5}$$

Then, maximum group benefit value (Q_j) was calculated based on Formula 6. Here, v is the weight value for the strategy that will create the maximum group benefit, and $(1 - v)$ is the minimum regret of the opposing viewers. The v value determined by the group decision; *v > 0.5* represents the majority preference, *v = 0.5* consensus and *v < 0.5* veto for maximum group benefit in the Vikor Method.

$$Q_j = \frac{v(S_j - S^*)}{S^- - S^*} + \frac{(1-v)(R_j - R^*)}{R^- - R^*} \tag{6}$$

All of the calculated S_j, R_j and Q_j values are ordered from the smallest to the biggest; after, acceptable advantage C_1 and acceptable stability C_2 clusters are defined. Clusters C_1 and C_2 are determined in order to the order of S_j, R_j and Q_j values. For taking place in the any alternative to take place in the C_1 set, it must provide the following formula.

$$Q(A_2) - Q(A_1) \ge DQ \tag{7}$$

$$DQ = \left(\frac{1}{(1-m)} \right), m: number\ of\ alternatives$$

According to the order of Q_j, if the A_2 alternative takes place after the A_1 alternative and provides the formula, then the A_1 decision point is in the C_1 group. This calculation method is applied to all Q_j values and it is determined whether the alternatives are in C_1 set. The set of acceptable stability (C_2) consists of alternatives that are in the same order in the entire order of S_j, R_j and Q_j. Alternatives in both sets C_1 and C_2 show stable decision points according to sequencing logic.

4. APPLICATION

In this study, five most purchased powder detergents were determined from top FMCG companies' annual reports and some related articles in literature. MATLAB R2018a software was selected as measurement tool because, it is very flexible and useful for R&D activities. Furthermore, it was understood that there is an insufficient number of papers to generate an algorithm by using a tool about Vikor Method in literature. The aim of the application is to detect the most appropriate detergent brand according to the sustainability dimensions by Vikor Method. The application of the Vikor Method to evaluate the identified powder detergent options under sustainability metrics was coded on MATLAB software.

First of all, five different powder detergent alternatives and 12 different criteria (see Table-1) have been defined from 14 selected highly cited sustainability reports and articles. The values in the Table-1 are determined from the annual reports of global detergent manufacturers, researchs in the literature and articles given as reference. Then, the decision matrix which includes data set has been entered into the software.

Table 1. Table of Powder Detergent Alternatives and Sustainability Evaluation Criteria

Products	1	2	3	4	5
Market share	2.5	4.8	14.8	10.9	4.9
Retail price/net weight	0.205	0.22	0.1015	0.096	0.08
Packing quality	2	1.6	2	1.6	1.6
Detergency	21.53	25.38	17.78	21.03	18.64
Active ingredient	11.68	10.72	13.46	9.73	15.49
Sodium carbonate built-up	10	7.66	9.16	7.87	7.78
Active alkalinity	6.37	6.73	5.65	7.28	7.33
Total phosphates	4.1	6	5.93	5.99	5.99
Sodium triphosphate	3	6	6	6	6
Foam height	3.94	1.72	4	2.5	2.56
Moisture	3.35	3.35	2.99	3.71	3.66
Fragrance	2	2	1	1.5	2

The alternatives were named as Detergent 1, Detergent 2, Detergent 3, Detergent 4 and Detergent 5, and the criteria based on sustainability metrics were defined as market share, retail price per net weight, packing quality, detergency, active ingredient, sodium carbonate built-up, active alkalinity, total phosphates, sodium triphosphate, foam height, moisture and fragrance which were detected during literature review. Then, the benefit vector considering effects of each criteria on sustainability was defined which is given as Table-2 below:

Table 2. Benefit Vector

Criteria	1	2	3	4	5	6	7	8	9	10	11	12
Benefit	1	0	1	1	0	0	0	0	0	1	0	1

As the next step, the arithmetic means of the importance given by the decision makers for the criteria were entered into the weight vector w (see Table-3).

Table 3. Weight Vector

Products	**1**	**2**	**3**	**4**	**5**
Weights based on market share	2.5	4.8	14.8	10.9	4.9

In case of the aim of benefit maximization and damage minimization, max_j and min_j values were calculated by data gathered from columns of the decision matrix. After, both calculations of the average group value (S_j) and the worst group value (R_j) were integrated as another part of MATLAB code which was followed by the calculation of maximum group benefit value (Q_j) and ascending ordering of S_j, R_j, Q_j values. At the end of the coding process, MATLAB was run and the outputs were given as below:

- The order of preference of different powder detergent alternatives based on defined criteria: 2, 4, 1, 5, 3.
- The most preferable powder detergent alternative due to sustainability metrics: 2.

The results show that the most effective criteria on preference rank are active ingredient and foam height without considering market share and retail price per net weight criteria. It can be inferred that ordering of alternatives basically considers value creation of the product per environmental effect. Under this view, although higher rate of active ingredient decreases the probability of preference of the product due to sustainability evaluation; however, foam height is an advantageous criterion for consumers more tending to prefer that product. Thus, this measurement can be represented as a rate of foam height effectiveness per unit of active ingredient. On the other hand, the least preferable powder detergent was detected as Detergent 3 because of containing the second highest rate of active ingredients, the highest rate of sodium carbonate built-up and the smallest rate of fragrance even though it has more effective amount of chemicals inside.

5. CONCLUSION

United Nations Brundtland Commision refers sustainability as “meeting human needs without compromising the ability of future generations to meet their own needs.”(United Nations, 1987) In addition to environmental issues, this concept also involves social and economic resources. Today, there is an increasing awareness of sustainability both in governments and populations. Many consumers tend to compare the product alternatives at first, and then prefer more sustainable one to avoid bringing damaging on ecology. Not only consumers, but also many companies started to take preventive actions against to consume resources, energy more than adequate amount in their manufacturing operations and waste creation especially in chemical-based processes. Detergent selection problem is important for sustainability due to detergents’ chemical production and intensive usage. According to literature research, it was investigated that the most consumed household laundry detergent type is powder detergent because, they can be supplied with higher volume in a package to reduce selling price and they can be used any amount as much as a consumer want. Within this study, powder detergents were evaluated with Vikor Method which is an effective method when decision-maker is not experienced how to make a preference and tried to decide with analyzing both quantitative and qualitative data. As a result, the most preferable powder detergent type was detected as creating more value for consumer per negative effect by active ingredients under sustainability perspective. As future directions of the study, the same analysis will be managed by more sustainability criteria and more alternatives combined powder, liquid and tablet detergents. Besides, decision-makers' brand preferences will be considered at the beginning of the analysis which make the data set more complex with unpredictable qualitative data.

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Predicting Kidney Tumor Subtype from Ct Images Using Radiomics and Clinical Features

Research Article

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Abstract

Purpose: This study aims to evaluate the performance of machine learning methods in predicting the subtype (clear-cell vs. non-clear-cell) of kidney tumors using clinical patient and radiomics data from CT images. Method: CT images of 192 malignant kidney tumor cases (142 clear-cell, 50 other) from TCIA's KiTS-19 Challenge were used in the study. There were several different tumor subtypes in the other group, most of them being chromophobe or papillary RCC. Patient clinical data were combined with the radiomic features extracted from CT images. Features were extracted from 3D images and all of the slices were included in the feature extraction process. Initial dataset consisted of 1157 features of which 1130 were radiomics and 27 were clinical. Features were selected using Kruskal Wallis – ANOVA test followed by Lasso Regression. After feature selection, 8 radiomic features remained. None of the clinical features were considered important for our model as a result. Training set classes were balanced using SMOTE. Training data with the selected features were used to train the Coarse Gaussian SVM and Subspace Discriminant classifiers.

Results: Coarse Gaussian SVM was faster compared to Subspace Discriminant with a training time of 0.47 sec and ~11000 obs/sec prediction speed. Training duration of Subspace Discriminant was 4.1 sec with ~960 obs/sec prediction speed. For Coarse Gaussian SVM, the AUC was found to be 0.86, while for Subspace Discrimination it was 0.85.

Conclusion: Both models produced promising results on classifying malignant tumors as ccRCC or non-ccRCC.

Keywords: Kidney Tumor, Clear-cell, Machine Learning, CT imaging.

1. INTRODUCTION

More than 400 000 patients are diagnosed with kidney cancer each year, more than 90% of them being renal cell carcinoma (RCC). RCC is known to be the most common type (75%) of kidney cancer as well having the highest mortality rate among genitourinary cancers. It has more than 10 histological and molecular subtypes and one of them is clear cell RCC (CCRCC) (Hsieh et al. 2017) .

Currently, a great effort is being out into the studies concerning how different kidney tumor morphology might affect the treatment process. Surgery, chemotherapy and targeted drugs are used for treatment and a variety of new, more effective drugs are continued to be developed. There has been a big improvement in the median survival of the disease in the past few years, thanks to the targeted drug development (Le and Hsieh 2018).

As for the diagnosis of renal cancer; laboratory tests, radiology and biopsy are used. Presently, biopsy is obligatory in order to deduce key information as whether the cancer is invasive, its grade, its stage and spread to lymph nodes. In addition to these, biopsy must be performed to identify specific proteins, genes and other factors which are unique to the tumor. These factors play an important role in prognosis prediction and in the construction of a treatment plan. They can also provide a clearer view on how to design a more effective drugs targeting specific intracellular pathways (Ökmen, Guvenis, and Uysal 2019).

Biopsy is a highly invasive diagnosis tool which carry a small risk of infection and bleeding. Moreover, for cancer cases, reaching a result might take several days. For these reasons, there is a need for obtaining the necessary information for diagnosis by using better tools.

Computed Tomography (CT) is widely used for clinical diagnosis, localization of pathology, observation of anatomical structure, surveillance of therapy evolution and planning the optimal treatment in cancer. CT is generally the first choice for imaging the evolution of renal tumor because it is more available than Magnetic Resonance Imaging (MRI) and it more useful than Ultrasound (US) Imaging (van Oostenbrugge, Fütterer, and Mulders 2018).

An emerging field, Radiomics, has the ability to provide many advantages in cancer imaging. It focuses on obtaining quantitative information from clinical images, which helps characterize the image phenotypes of the tumor in a more detailed way. Radiomics is concerned with reaching useful diagnostic, prognostic and predictive information.

One of the the main objectives of the presented work is to perform a comparison among existing machine learning methods for the classification of tumor histologic subtypes of renal cell carcinoma (RCC) patients. It also focuses on the question of which radiomic features and patient clinical data provide meaningful information about the histologic subtypes.

2. LITERATURE REVIEW

In a 2019 study (Han, Hwang, and Lee 2019), Convolutional Neural Networks were used to classify the tumor histologic subtypes of RCC cases. The data set included clear-cell, chromophobe and papillary subtypes. The model was fed with three-phase CT images and one slice from each phase was used. AUC values for differentiating clear-cell from non-clear-cell, papillary from non-papillary and chromophobe from non-chromophobe were; 0.93, 0.91 and 0.88 respectively.

Another paper by Kocak et al. focused on classifying the tumors as ccRCC or Non-ccRCC, as well as differentiation of ccRCC, pcRCC and chcRCC from each other. Artificial Neural Networks classifier predicted the subtypes as ccRCC or non-ccRCC with an AUC of 0.92, while the AUC of Support Vector Machine classifier was 0.79. Both of them performed worse in the three-class models (Kocak et al. 2018).

Zhnag et al. evaluated several models incorporating SVMs for classifying tumors as ccRCC or non-ccRCC, and chromophobe or papillary RCC. Slices with the largest cross-sectional area of the lesion from 3-phase CT images were used. Top 3 features were selected by Mann-Whitney U-tests, ROC curves and Pearson's correlation coefficient methods. An SVM with a nonlinear radial basis function kernel was implemented. Best results were achieved using the corticomedullary phase images. AUC for ccRCC vs. non-ccRCC classification was 0.94 (Zhang et al. 2019).

Hoang et al., conducted a study which used random forest models for three classifications: oncocytoma vs. RCC, oncocytoma vs. ccRCC and papillary vs. ccRCC. Three consecutive slices containing the largest cross-sectional area from each of the four phases of MR images of 142 lesions from 41 patients were included. Pairwise Wilcoxon rank test, modified false discovery rate adjustment, Lasso regression were used for feature selection. ccRCC cases were distinguished from oncocytomas with an average accuracy of 77,9% (Hoang et al. 2018).

3. MATERIALS AND METHODS

Data Sets

CT images and patient clinical data from the Climb 4 Kidney Cancer-Kidney Tumor Segmentation Challenge (C4KC-KiTS) database (Clark et al. 2013; Heller et al. 2019) were acquired. 210 patients were included in the C4KC-KiTS database. In this study, 192 of the cases which had malignant tumors were used.

Image Pre-processing

Resampling, intensity normalization and gray level discretization were applied before starting the feature extraction process. Images had different slice thicknesses (0.5 mm to 5 mm) and different pixel sizes (0.438 mm to 1.04 mm). After reconstruction and resampling, 1 mm × 1 mm × 1 mm spatial resolution was achieved. Python software was used to perform resampling, and the new values of the resampled images were obtained by Cubic B-Spline interpolation method (Wang et al. 2011). Z-score normalization was used for the normalization of image intensity values. For gray level discretization, bin width was adjusted to be 0.01 on 3D Slicer software(Fedorov et al. 2012). Gray level discretization lessens the heterogeneity influences on the images, resulting from acquisition and reconstruction protocols(Larue et al. 2017).

Feature Extraction

Radiologic images carry relevant and significant clinical information (Tomaszewski et al. 2021). Feature extraction is an important step for finding the link between disease and image attributes, on the grounds that its enablement to obtain solid, quantitative representations.

Features were extracted using PyRadiomics extension on 3D Slicer. Three types of images were subject to feature extraction: original, Laplacian of Gaussian (LoG) and wavelet-transformed. Laplacian of Gaussian filter values were 2 mm, 4 mm, and 6 mm in order to explain patterns with various sizes.

After all radiomic features were extracted, certain patient clinical data were added to get a combined data set. Clinical data included information such as age, sex, body mass index; as well as presence of several diseases, alcohol and tobacco use. Afterwards, the combined data were split into training and test sets as 85% and 15% respectively. As a result, 162 training cases included 128 clear-cell RCC and 34 other histologic subtypes (chromophobe, papillary, clear-cell papillary, multilocular cystic, urothelial, wilms). Further, 15 of the test cases were clear-cell and the remaining 15 were other (chromophobe, papillary, clear-cell papillary).

Feature Selection

Feature selection process was executed on Matlab (R2021b) software. Kruskal-Wallis (KW) test was conducted as the first step of feature selection. KW compares the medians of the groups of data to determine if the samples come from the same population. In this case, each feature was tested for its ability to differentiate between the data classified as clear-cell and other with p = 0.05. Only 111 features among the 1157 were decided to be relevant. Moreover, none of the patient clinical features were selected.

Secondly, least absolute shrinkage and selection Operator (LASSO) was used at the next phase for selecting features. Lasso is an improved version of ordinary least squares estimates in regression analysis combining subset selection and ridge regression (Tibshiranit 1996). It causes some regression coefficients to shrink and set some of them to zero. At the end, coefficients belonging to the less important features become zero. Lambda with the minimum standard error was chosen to obtain the optimal set of coefficients. Subsequently, 8 features were selected as the most relevant for our model.

Model Training and Evaluation

Coarse Gaussian Support Vector Machine and Subspace Discriminant classifiers were trained with the selected features in the Classification Learner App of Matlab. SVM classifier aims to find the optimal hyperplane in the N-dimensional space that distinctly classifies the data points. The optimal hyperplane can be described as the most distant of all possible ones to both classes. The data points closest to this hyperplane are defined as support vectors. In case simple hyperplanes do not show sufficient separation performance. Hence, kernels are reproduced which use several functions. In this study, the SVM classifier with a Gaussian (radial basis fuction) kernel was used. Box constraint level was 1 and kernel scale was chosen as 11 for the classifier. 5-fold cross validation was used in the training process.

Discriminant classifiers assume that different classes have different Gaussian distributions. Their objective is to classify the data points while minimizing the classification cost. Ensemble learning combines several classifiers to improve the prediction performance. Each learner, discriminant classifier, is trained using a random subset of features among the selected ones. At the end, the best model is introduced. The model included 30 learners with 4 subspaces and the training was performed using 5-fold cross validation. Previously reserved test data set was used to test the model performances. Accuracy and area under the curve (AUC) for both models were calculated for evaluation.

4. RESULTS

Feature Extraction and Selection

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In addition to the 27 clinical features which can be seen on Table 1, 1130 radiomic features were extracted from the CT images, adding up to 1157 features in total. Among the radiomic features; 744 were from wavelet-transformed images with 8 distinct filters and 6 classes of features (first-order, gray level dependence matrix (gldm), gray level co-occurrence matrix (glcm), gray level run-length matrix (glrlm), gray level size zone matrix (glszm) and neighboring gray tone difference matrix (ngtdm)). Laplacian of Gaussian (LoG) filtered images produced 279 features, while 107 features were extracted from original images.

Table 1. List of clinical features

Feature Name	Feature Name
gender	malignant_lymphoma
body_mass_index	localized_solid_tumor
myocardial_infarction	metastatic_solid_tumor
congestive_heart_failure	moderate_to_severe_liver_disease
peripheral_vascular_disease	smoking_history_never_smoked
cerebrovascular_disease	smoking_history_previous_smoker
copd	smoking_history_current_smoker
connective_tissue_disease	chewing_tobacco_use_never_or_not_in_last_3mo
peptic_ulcer_disease	chewing_tobacco_use_quit_in_last_3mo
uncomplicated_diabetes_mellitus	alcohol_use_two_or_less_daily
diabetes_mellitus_with_end_organ_damage	alcohol_use_never_or_not_in_last_3mo
chronic_kidney_disease	alcohol_use_more_than_two_daily
hemiplegia_from_stroke	radiographic_size
leukemia	

Table 2. Selected features for the models

Image Type	Feature Name
Original	First Order - Interquartile Range
Original	GLCM - IDN
Log filtered (sigma: 2 mm)	3D GLRLM – Long Run Emphasis
Log filtered (sigma: 2 mm)	3D GLRLM – Run Variance
Log filtered (sigma: 2 mm)	3D GLDM - Dependence Variance
Log filtered (sigma: 4 mm)	3D First Order - Kurtosis
Log filtered (sigma: 6 mm)	3D First Order - 90^{th} Percentile
Log filtered (sigma: 6 mm)	3D First Order - Maximum

As a result of the Kruskal-Wallis test, 111 features were eliminated as they were not significant for the problem in question. The process was followed by Lasso regression to detect the most useful features, which left 8 of them (see Table 2) to be used in the classification models. These included: First Order Interquartile Range, GLCM Inverse Difference Normalized and GLRLM Run Variance. Prior to model training, new instances belonging to the minority class were created synthetic minority oversampling technique (SMOTE) to balance the training set. Ultimately, both classes consisted of 128 cases and the models were trained with a total number of 256 cases.

Performance Evaluation

Coarse Gaussian SVM was faster compared to Subspace Discriminant with a training time of 0.47 sec and ~11000 obs/sec (observations per second) prediction speed. Training duration of Subspace Discriminant was 4.1 sec with ~960 obs/sec prediction speed. For Coarse Gaussian SVM; validation accuracy was 67,6% while the accuracy of test was 80%, with and AUC of 0.86. Similarly, Subspace Discriminant had 68,8% validation accuracy and 80% test accuracy; AUC was 0.85. Fig. 1 shows the confusion matrices of the two models. The recieving operatör characteristic (ROC) curves can be seen on Fig. 2.

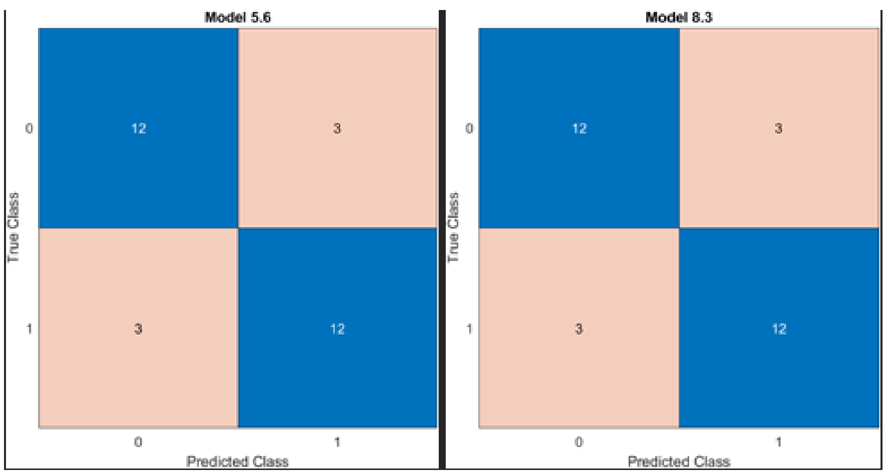

Figure 1. Confusion matrices for Coarse Gaussian SVM and Subspace Discriminant on test data set.

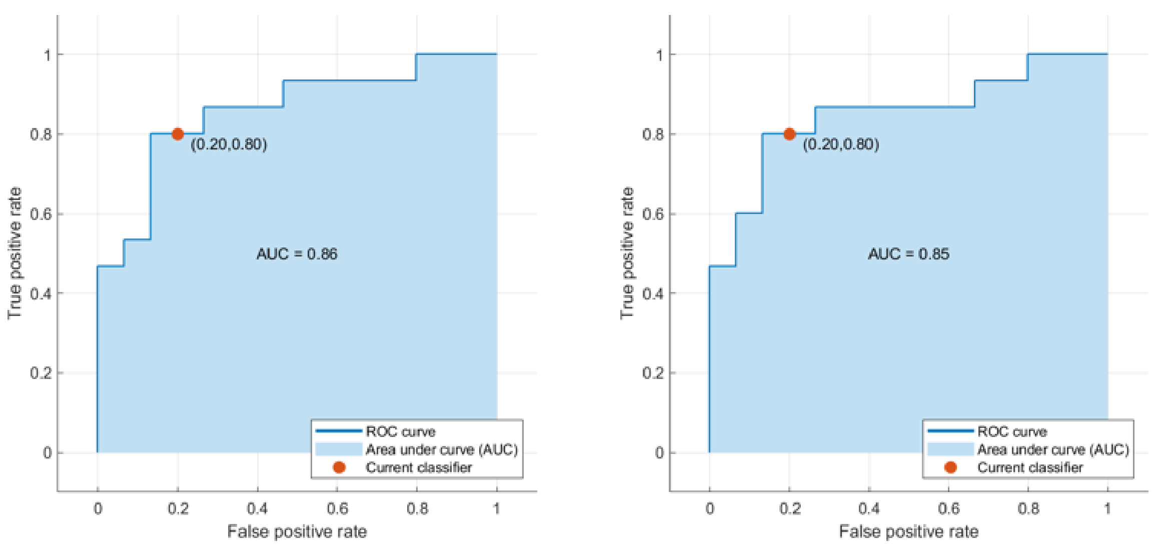

Figure 2. ROC curves of classification models on the test dataset.

5. DISCUSSION

This study investigates the usefulness of machine learning algorithms for malignant kidney tumor histologic subtype classification. In consideration of the performance evaluation, both models demonstrated promising results when classifying the tumors as clear-cell RCC or non-clear-cell RCC. Nonetheless, Coarse Gaussian SVM might be slightly more preferable because of its training and prediction speed.

Our methodology produced similar results as other studies focusing on the similar questions. Therefore, we can deduce that machine learning in radiomics is a viable method for determining the histologic tumor subtype of renal tumors. However, our study differs from others with the data source which was used, as well as other dimensions such as having a high number of cases. Dissimilar to the studies of Kocak B.et al., Zhang G. et al., Hoang et al. and Han et al., this study used all slices of the CT images as an input to the models. Furthermore, we tested if the inclusion of patient clinical data would be useful. Our study found that the specific clinical data included did not have an impact on the classification.

In the future, improved models might be constructed by the addition of blood and urine biomarkers as clinical features. Increasing the size of the data set to achieve better representation of other histologic subtypes can also be considered in order to answer different classification problems.

6. CONCLUSION

We proposed two different models bases on machine learning algorithms to label the malignant tumor cases as ccRCC or non-ccRCC using relevant radiomic features extracted from renal CT images. Both models produced similar results which can be considered as encouraging. These types of classifiers were considered for the first time. This work supports the objective of having a fast and non-invasive technique in the diagnosis process of RCC patients; specifically for deciding the tumor histologic subtype.

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Characterization of Coarse Recycled Aggregates Produced from Concretes with Different Strength Levels

Research Article

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Abstract

With the acceleration of Urban Renewal Program, particularly in large cities of Turkey, the problem of finding land-fills and eliminating construction waste with the least environmental pollution necessitates its value-added recycling. However, the presence of adhered weak mortar layer, comprising 20-70% of recycled concrete aggregate (RCA), limits the use of RCA or lowers its inclusion level in concrete mixtures. Within the scope of this study, limestone- and basalt-bearing RCA obtained from 6 different concrete mixtures with three different water/cement ratios (0.45, 0.60, 0.70) were prepared and their water absorption, specific gravity, dense and loose unit weight, flatness indices, Los Angeles degradation values were determined. The results showed that, increasing w/c ratio of the parent concrete increased water absorption of the resultant RCA. However, the specific gravity, unit weight, abrasion resistance and flakiness index of RCA were decreased by increasing w/c ratio of the parent concrete.

Keywords: Recycled Concrete Aggregate, Parent Concrete Strength Level, Water Absorption, Degradation Resistance, Flakiness Index.

1. INTRODUCTION

Among the building materials used today, the most preferred one is undoubtedly concrete. Since, the annual concrete need in the world is approximately 4.5 billion tons, the yearly concrete consumption per person is 0.7 tons on average. The fact that urbanization and the world population has continued to increase with the rapid increase in the last century shows once again the importance of concrete and the materials that make up concrete, one of the most commonly used building materials in many parts of human life. The concrete industry, which uses 12.6 billion tons of raw materials in total each year, is the world's largest consumer of natural resources. In addition to the approximately 3 billion tons of raw materials needed each year for cement production, aggregate mining, processing and transportation consume a significant amount of energy and adversely affect the ecology of the planet (Mehta, 2001 and 2002).

Recycled aggregate, which has been used in construction since the end of the Second World War, is a material that can be used in the stabilization of road constructions. Recycled aggregate provides very good advantages in terms of being environmentally friendly and economical in the construction sector. Waste from demolition and construction works poses a major problem as they accumulate gradually and increase over time, so recycled aggregate offers an excellent alternative solution to this problem. Sustainable concrete should be considered as the main strategy for the construction industry. It is important to decrease energy consumption associated with carbon dioxide emissions that cause greenhouse effect (Mohammed et al., 2018).

According to the “World Commission on Environment and Development", sustainability means “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Naik & Moriconi, 2005). The sensible use of natural resources obtained using waste materials and the reduction of natural aggregate consumption as well as the lower environmental impact achieved by low carbon emissions represent two main activities aiming at meeting the requirements of sustainable reinforced concrete construction (Movassaghi, 2006).

The use of recyclable materials is increasing worldwide, with many impacts on economic, environmental and technological developments. Recyclable materials can break down, erode or be destroyed by nature if not reused. (Asmatulu & Asmatulu, 2011). Environmental impacts from extracting non-renewable raw materials include deforestation, soil loss, air pollution, reduction and pollution of water reserves. The construction industry has a large share of 40% in all materials that cause these effects (Pacheco-Torgal, 2013).

The gradual decrease in aggregate resources, deterioration of the natural environment, increase in environmental pollution and increase in aggregate cost have led to new searches. In this context, crushing waste concrete and evaluating it as recycled concrete aggregate is extremely important in terms of protecting the environment. The use of waste concrete as recycled aggregate is an important gain in terms of both reducing environmental pollution and contribution to the national economy. For this reason, adding economic value to waste concrete comes to the front today (Demirel et al., 2015). With the legal obligation regarding of recycling, new developments are taking place in the recycling field in industrial sector. This is positive for economic development and employment. Raw material production is provided more easily with recycling. In other words, the preparation of the waste material for production requires less processing than the production from nature. This provides energy savings (Öztürk, 2005).

The acceptability of recycled aggregate is not accepted by consumers because of their lack of trust to recycling activity. As an alternative to natural aggregate, the environmental and economic advantages of using recycled aggregate are greatly affected by economic reasons. By way of example, the choice between recycled and natural material depends on their quality and prices. The quality of recycled aggregate concrete may be the same as the concrete that containing non-recycled aggregate, but recycled aggregate concrete is considered with doubt. Therefore, recycled concrete aggregate may not be desired when the price of such aggregate is much lower than the natural material, even if the recycled aggregate meets the given quality. A major obstacle is the change in the quality of recycled aggregate, which can be easily overcome by construction and demolition waste processing facilities. Another restriction to the reuse of recycled concrete aggregate in construction is the lack of a well-developed gathering, processing plants and transportation. Recycled aggregate must be available in usable quantities. This should be a top priority in supporting the reuse of recycled aggregate in the construction industry, as potentially usable material constraints will have a significant impact on decision-making processes. In most cases there is a concern due to the lack of confidence in the technical feasibility of recycled aggregate. If the product fulfills with high quality standards, it can be considered as a realistic alternative to natural aggregate in structural concrete production (Tam et al., 2018).

The reasons why recycling aggregate is not used in concrete mixtures can be listed as follows (Batman, 2018):

- Problems related to quality control due to insufficient technology in recycling aggregate production processes.
- Lack of towards the recycling aggregate which can be overcome by raising the awareness of the consumer. For example; information about the use of recycled concrete aggregate instead of natural aggregate in low strength concretes can be provided and an awareness effect can be created by explaining its positive effects on the environment.
- It is not economical to open a facility in places where there is not enough demolition waste due to the insufficient facilities.
- Inadequate standards regarding recycling aggregate is another problem.

According to Malešev et al. (2014), recycled aggregate is less advantageous than natural aggregate in terms of physical characteristics. The grains are irregular, mostly angular, rough and with a cracked surface and porous. These grain properties significantly affect the workability of fresh concrete as well as the strength and permeability of the hardened concrete. (Malešev et al., 2014).

According to Padmini et al., (2009), RCA particle is more irregular and has a rougher surface than natural aggregate. Concrete that made from RCA needs more water than normal concrete a given workability. Beside, its density, compressive strength and elastic modulus are lower than that of normal concrete (Padmini et al., 2009). The RCA produced from demolishing waste is generally contaminated with salts, bricks, wood, metal, plastic, cardboard and paper. It has been shown that contaminated aggregate can be used instead of natural coarse aggregates in concrete after separation and screening from the waste. However, as in natural aggregates, features such as water absorption, grain size distribution, grain shape, and abrasion resistance should be tested in recycled aggregates to measure their quality (Rao et al., 2007).

According to a study conducted by the Environmental Council of Concrete Organizations, an estimated 60% savings have been achieved by using RCAs instead of natural aggregates. In a study conducted at Purdue University in the USA, it has been reported that the use of RCA has a cost reduction potential of 2.26-2.93 $ per ton in pavement concrete (Verian et al., 2018).

Coarse recycled concrete aggregate (RCA) is composed of the natural coarse aggregate and the adhered-mortar on its surface. The presence of the residual mortar on RCA is inevitable because complete removal of it would prove costly and detrimental to the integrity of the natural aggregate. Although, as cited by Volz et al. (2014), the quality of RCA is not always dependent on the characteristics of the adhered-mortar (Nagataki et al., 2012), there are many reports indicating that the residual mortar is the cause of high porosity, considerable high water-absorption and low specific gravity of RCA compared to those of virgin aggregate. In general, it is demonstrated that the negative effect of RCA on the properties of resultant concrete becomes considerable when the substitution level of RCA (in place of virgin aggregate) is beyond 25% (Debieb et al., 2010, Fonseca et al., 2011, Etxeberria et al., 2007, Huda et al., 2015). However, it should be emphasized that the substitution level at which the adverse effect of RCA on concrete properties (if any) becomes apparent, also depends on the characteristics of RCA itself. For instance, reducing maximum aggregate size from 20mm to 15mm, through mechanical treatment (additional grinding of RCA) may result in a considerable increase in RCA substitution level without suffering the properties of resultant concrete (Volz et al., 2014). In short, for a better understanding of the RCA and to predict its effects on concrete, the components of these composite material must be discovered separately (Nagataki et al. 2012).

2. EXPERIMENTAL STUDY

Materials

Aggregates

In order to make more accurate comments about the effect of RCA on concrete properties, it is necessary to know properties of the ingredients and properties of the parent concrete. Within the scope of this study, RCAs were obtained from 6 different concrete mixtures, with three different water/cement ratios (0.45, 0.60, 0.70) prepared with limestone and basalt aggregates. The information about the size of the aggregate grains used is as follows: Basalt aggregate has been used with two different particle size fractions, 5-15- and 15-25- mm and limestone aggregate with 0-5-, 5-15- and 15-25-mm size fractions. The physical properties of the aggregates used are shown in Table 1.

Table 1. Physical properties of coarse and fine aggregates in parent concrete

Properties	Limestone Aggregate			Basalt Aggregate	
	0-5 mm	5-15 mm	15-25 mm	5-15 mm	15-25 mm
Dry Rodded Unit Weight (kg/m^3)	1889	1573	1548	1646	1590
SSD Specific Gravity	2.65	2.68	2.71	2.81	2.83
Water Absorption Capacity (%)	0.92	0.30	0.23	0.45	0.40

Superplasticizer

Properties of the polycarboxylate ether-based superplasticizer admixture obtained from its manufacturer are given in Table 2.

Table 2. Properties of superplasticizer admixture

Alkali Content (%) (Na_2O)	Density (g/cm^3)	Solids Content (%)	Chloride Content (%)	pH at 25 °C	Operating Range (%)*
<5	1.096	34.63	0.011	5.87	0.6-2.0

*By weight of cement

Cement

In the experimental study, a CEM I 42.5R cement was used. The chemical, mechanical and physical properties of the cement are given in Table 3.

Table 3. Chemical composition, physical and mechanical properties of cement

Chemical Composition (%)		**Physical Properties**	
SiO_2	19.32	Specific Gravity	3.12
Al_2O_3	5.21	Blaine Specific Surface (cm^2/g)	3674
Fe_2O_3	1.95	Initial Setting Time (min)	150
CaO	63.02	Final Setting Time (min)	200
MgO	2.02	**Compressive Strength (MPa)**	
Na_2O	0.36	2-day	24.0
K_2O	0.83	7-day	39.3
SO_3	3.12	28-day	49.5
Loss on Ignition	3.67		
Cl	0.0074		
Insoluble Residue	0.63		
Free CaO	1.06		

Mix proportions of parent concrete

A total of 6 different concrete mixtures were prepared to obtained RCA. These mixtures had three different w/c ratios (0.45, 0.60, 0.70) and they were prepared with limestone or basalt coarse aggregates. The actual mix proportions of concrete mixtures are given in Table 4. In the abbreviations of the mixtures, the terms “LS” and “B” refer to limestone and basalt coarse aggregates, respectively, while the numbers indicate the w/c ratio of parent concrete.

Table 4. The actual mix proportions of parent concretes (kg/m^3)

Mixture	W/C Ratio	Cement	Water	Aggregate, SSD Limestone			Aggregate, SSD Basalt		Unit Weight
				0-5 (mm)	5-15 (mm)	15-25 (mm)	5-15 (mm)	15-25 (mm)	
RCA-LS 45	0.45	385	172	1018	420	425	0	0	2420
RCA-LS 60	0.60	286	171	1046	432	440	0	0	2375
RCA-LS 70	0.70	287	201	1009	418	423	0	0	2338
RCA-B 45	0.45	373	167	986	0	0	426	429	2381
RCA-B 60	0.60	280	168	1024	0	0	449	452	2373
RCA-B 70	0.70	282	197	991	0	0	428	431	2329

3. RESULT AND DISCUSSION

After determining the 28-day compressive strength of the 150 mm cube samples kept in the curing pool for 28 days, they were crushed using a jaw crusher to obtain RCA. The 15-25 mm size fraction of RCA was separated to be used in further investigations. The compressive strength of parent mixtures was determined in accordance with TS EN 12390-3 standard. The water absorption capacity and specific gravity (TS EN 1097-6), particle size distribution (TS EN 933-1:2012(EN)), bulk density (TS EN 1097-3), resistance to fragmentation (TS EN 1097-2), flakiness index (TS EN 933-3) of the RCA were also determined.

Compressive strength of parent concrete mixtures

The compressive strength of parent mixture is given in Table 5. As it was expected the strength of concrete reduced by increasing w/c ratio. Thus, strength values in the range of 25.4 MPa to 55.8 MPa were obtained. Moreover, for the same w/c ratio, basalt coarse aggregate-bearing mixtures showed somewhat greater compressive strength than their limestone coarse aggregate-bearing counterparts.

Table 5. Compressive strength of parent concrete mixtures

Mixture	W/C Ratio	28-day Compressive Strength (MPa)				
		Sample 1	Sample 2	Sample 3	Average	Standard deviation
RCA-LS 45	0.45	51.48	48.86	49.38	**49.91**	**1.13**
RCA-LS 60	0.60	33.25	32.63	32.32	**32.73**	**0.39**
RCA-LS 70	0.70	25.23	25.79	25.22	**25.41**	**0.27**
RCA-B 45	0.45	54.99	56.47	55.96	**55.81**	**0.61**
RCA-B 60	0.60	33.12	34.98	34.76	**34.29**	**0.83**
RCA-B 70	0.70	26.60	28.40	27.90	**27.51**	**0.76**

Particle size distribution

Sieve analysis test results of the coarse aggregates used in the parent mixtures and RCAs are given in Table 6.

Table 6. Particle size distribution of aggregates

Aggregate Type	Percent Passing			
	31.5 mm	25 mm	20 mm	16 mm
Limestone	100	99	57	0
Basalt	100	99	46	0
RCA-LS 45	100	77	52	0
RCA-LS 60	100	81	65	0
RCA-LS 70	100	78	59	0
RCA-B 45	100	76	53	0
RCA-B 60	100	80	64	0
RCA-B 70	100	79	65	0

Mechanical and physical properties of aggregates

The water absorption capacity, flakiness index, resistance to fragmentation, unit weight and specific gravity of aggregates are given in Table 7.

Table 7. Water absorption capacity, flakiness index, resistance to fragmentation, unit weight and specific gravity of aggregates

Aggregate Type	Water Absorption (%)	Flakiness Index (%)	Fragmentations Resistance	Unit Weight (kg/m^3)		Specific Gravity	
			Weight Loss (%)	Compacted	Loose	Dry	SSD
Limestone	0.23	20.15	26,50	1548	1466	2.69	2.71
Basalt	0.4	12.28	12,83	1590	1521	2.82	2.83
RCA-LS 45	5.76	33.71	26,94	1291	1200	2.36	2.46
RCA-LS 60	6.58	19.6	30,52	1238	1092	2.23	2.39
RCA-LS 70	7.26	18.03	31,98	1210	1061	2.19	2.37
RCA-B 45	5.32	29.18	18,25	1349	1235	2.42	2.53
RCA-B 60	5.97	13.82	24,80	1242	1171	2.29	2.42
RCA-B 70	6.93	14.94	29,10	1219	1097	2.22	2.39

As it can be seen from Table 7. with increasing w/c ratio of the parent concrete results in an increase in water absorption capacity of RCA. While the water absorption capacity limestone and basalt aggregates are below 0.5%, the water absorption capacity of the coarse RCAs containing these aggregates is in between 5.32% and 7.26%. Higher water absorption capacity in RCAs is arisen from the presence of adhered mortar on RCA.

The flakiness index of RCAs prepared from the parent concrete mixtures with 0.45 w/c ratio was higher than other RCA. In general, the flakiness index of the RCA reduced by increasing the w/c ratio of the parent concrete. The fact is more pronounced in basalt RCA.

It is seen that RCAs prepared from the parent concrete mixtures with higher w/c ratio also have higher Los Angeles coefficients. It was observed that the Fragmentations resistance of RCA obtained from 0.45 w/c ratio mixtures was closer to the parent aggregate. However, increasing the w/c ratio of the parent concrete increased the Los Angeles loss on weight of the aggregate. The fact arises from the increased adhered mortar on RCA upon increasing w/c ratio of the parent concrete. Compared to the Los Angeles loss on weight of limestone aggregate, limestone RCA showed at most 21% higher weight loss. The corresponding value for basalt RCA was around 126%.

The specific gravity and unit weight of RCAs reduced with increasing w/c ratio of the parent concrete. Compared to the dry bulk specific gravity of corresponding parent aggregates, the specific gravity of limestone RCA was 19% lower. The corresponding value was 21% for basalt RCA.

5. CONCLUSIONS

For the material used and tests applied the following conclusions were drawn:

- The water absorption capacity of RCA was found to be higher than that of corresponding parent aggregate arisen from the presence of adhered mortar on RCA. Increasing the w/c ratio of the parent concrete from 0.45 to 0.7 caused an increase in the water absorption capacity of limestone RCA from 5.76% to 7.26%. The corresponding values were 5.32% and 6.93% for basalt RCA.
- Parent concrete mixtures with the highest w/c ratio (0.7) resulted in RCA with the lowest unit weight. Besides, using basalt in parent concrete led to higher RCA unit weight compared to limestone-incorporating RCA
- The RCAs prepared from 0.45 w/c ratio mixtures showed the highest amount of flaky particles. The fact was more pronounced in limestone RCA than basalt RCA.
- The Los Angeles weight loss of limestone RCA prepared from 0.45 w/c ratio parent mixtures was very close to that of the natural limestone aggregate. This was not the case in the RCAs prepared from parent concrete mixtures having higher w/c ratio, irrespective of the aggregate type of parent mixture. The difference between the Los Angeles weight losses of limestone aggregate and limestone RCA was around 21%. The corresponding value for basalt aggregate and basalt RCA was considerably high (126%).

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