International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I1P222

Volume 69 Issue 1, 139-146, January 2021


# Solid-State Welding Techniques For Polymeric Materials: A State of The Art Review And Future Prospective

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**Abstract**

*The polymers are highly encouraged in engineering applications due to the properties of the excellent material with lightweight structural formations. The joining/welding of the polymeric materials is one of the most needful assembly operation techniques, structures formations, and repairs. The conventional joining techniques like; arc welding or gas welding are not fit for the welding of polymeric materials as they can burn the materials. There are some solid-state joining techniques available that have been largely reported in previous studies. Friction welding (rotary friction welding, linear friction welding, friction stir welding, friction spot welding, and friction stir spot welding), ultrasonic welding, laser welding, and resistance welding are some of the available welding techniques which are reported previously for innovative applications. The present study is a state of the art review of the solid-state welding techniques for the joining of polymeric materials. Also, this study highlights the direction of future studies for the welding of polymeric materials.*

**Keywords:** *Friction stir welding, ultrasonic welding, laser welding, resistance welding, joining, Innovation*

## I. Introduction

Solid-state welding is the modern manufacturing processes that accomplish the joining of similar and similar structures with high mechanical performances [1]. Especially for polymeric materials, it is difficult to use the conventional welding process, such as arc welding and gas welding [2]. The solid-state welding techniques offer the joining of polymeric materials with good joint strength [3]. Friction welding (rotary friction welding, linear friction welding, friction stir welding, friction spot welding, and friction stir spot welding), ultrasonic welding, laser welding, and resistance welding are mostly reported in previous studies for the assembly, structural formation, and repair/maintenance applications [4], [5]. The previous studies have outlines the innovative engineering applications of the solid-state welding techniques for polymeric materials [6], [7]. It has been reported that friction stir welding is one of the efficient solid-state welding techniques for polymeric joining [8]. A novel approach to the friction stir welding process has been reported with the use of the robotic arm by using a robotic platform. Microwave welding is also an efficient method of joining, which has been reported for the joining of micro-fluidic devices [9]. In accordance with the friction stir welding process, the study has been reported for the heat-assisted friction stir welding process for joining of polymeric composite materials [10]. Laser welding is also one of the innovative solid-state welding techniques which offer the joining of disposable packaging materials for microfluidic biochips. The use of nanomaterials is of great importance as it can slightly improve the welding characteristics [11]. It has been reported that microwave welding can provide the localized heat for the joining of carbon nanotube-polymer for engineering applications [12], [13]. The study has revealed the use of radiofrequency heating on polymeric materials material for rapid welding. Mechanical properties of the weld joins have been improved by using graphene oxide in the case of resistance welding [14]. The welding of similar polymeric materials can be accomplished easily by using the regular solid state welding processes, but it requires the refinement in the process as well as the materials for high mechanical performances. The previous studies have been delivered the solution for improving the weldability of the polymeric based materials by modifying their melt flow behavior [15], [16]. The welding if melt flow compatible dissimilar materials do not require the special machine modification or setup modification. Also, the welding performances of the melt flow compatible thermoplastic by friction based welding process were reported with good mechanical performances [17], [18]. The previous studies have been reported the outstanding application of the solid-state welding processes in transportation industries, artificial neural network applications, airframe structural applications, and aerospace applications [19][20].

It is evident from the literature survey that solid-state welding techniques have been reported for numerous innovative applications [21]. The studies have been reported mostly to modify the tooling, machine, setup, and materials modifications that are needed to be explored in a

comprehensive manner for innovative applications. The present study is a state of the art review of the solid-state welding techniques for the joining of polymeric materials. Also, this study highlights the direction of future studies for the welding of polymeric materials.

## II. Friction stir welding

Friction stir welding is one of the most adopted technologies for the formation of simple strictures in automobile, construction, and aerospace applications. The output and direction of the past studies have been reviewed using the VOSviewer database (obtained from www.webofknowledgwe.com). A total of 162 studies have been reported by putting the keywords "friction stir welding of the polymer." Fig. 1 shows that studies have been reported mostly for friction stir welding with the investigations of the tool geometry, rotational tool speed, tensile strength, morphology, mechanical behavior of joint.

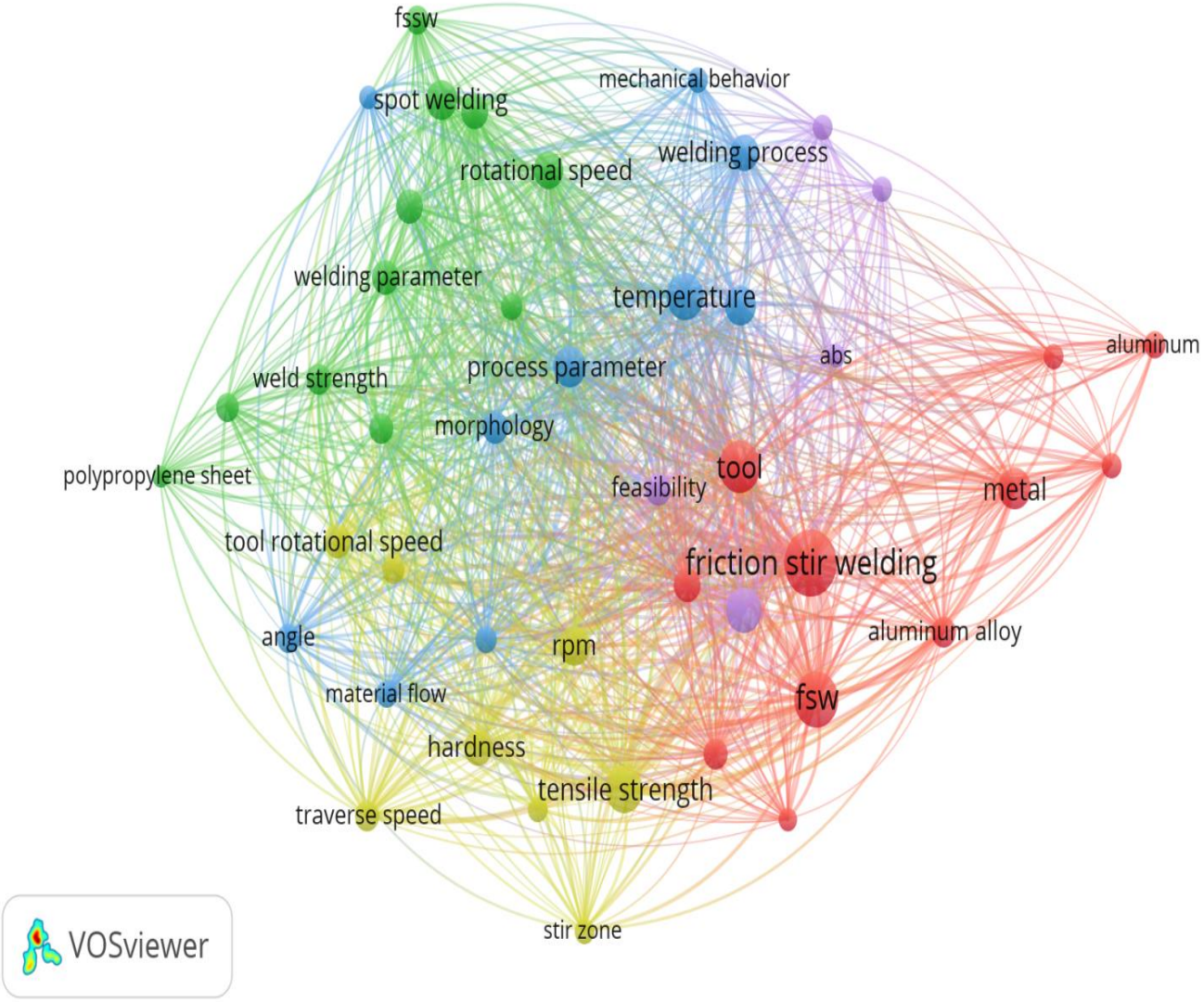


**Fig. 1 Bibliographic relational map analysis for keyword "friction stir welding of polymer" (database source: www.webofknowledge.com)**

Fig. 2 shows the relation of the friction stir welding process with the other reported terms. The previous studies have mostly been conducted for the investigation of friction stir welding of the polymers with the variation of the process parameters. Future studies may be explored for the friction stir welding of polymeric materials with investigations of the joint strength, melt flow behavior, dissimilar materials joining, materials flow, polycarbonate sheet joining, polyamide joining, reinforcement of aluminum, and other metal, and investigations of heat and plunge depth.

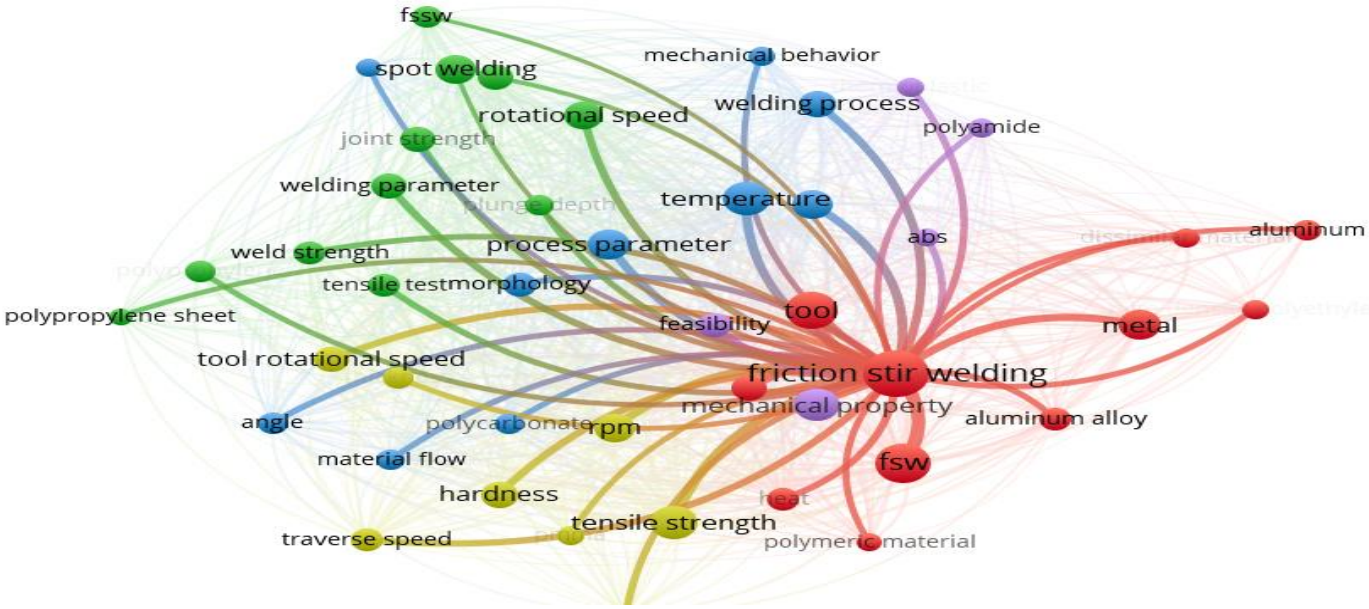


**Fig 2. Bibliographic map based gap analysis for friction stir welding of polymers**

### III. Ultrasonic welding

Ultrasonic welding has been shown its promising prospects in potential engineering applications. Using the web of science database, a total of 217 studies have been reported for the keyword "ultrasonic welding of the polymer." Fig. 3 shows that the previous studies have been reported for the ultrasonic welding with an investigation related to industrial applications, polymer joining, mechanical properties, carbon fibre, aluminum, welding time, quality, measurements, injection molded parts, polyamides, etc.

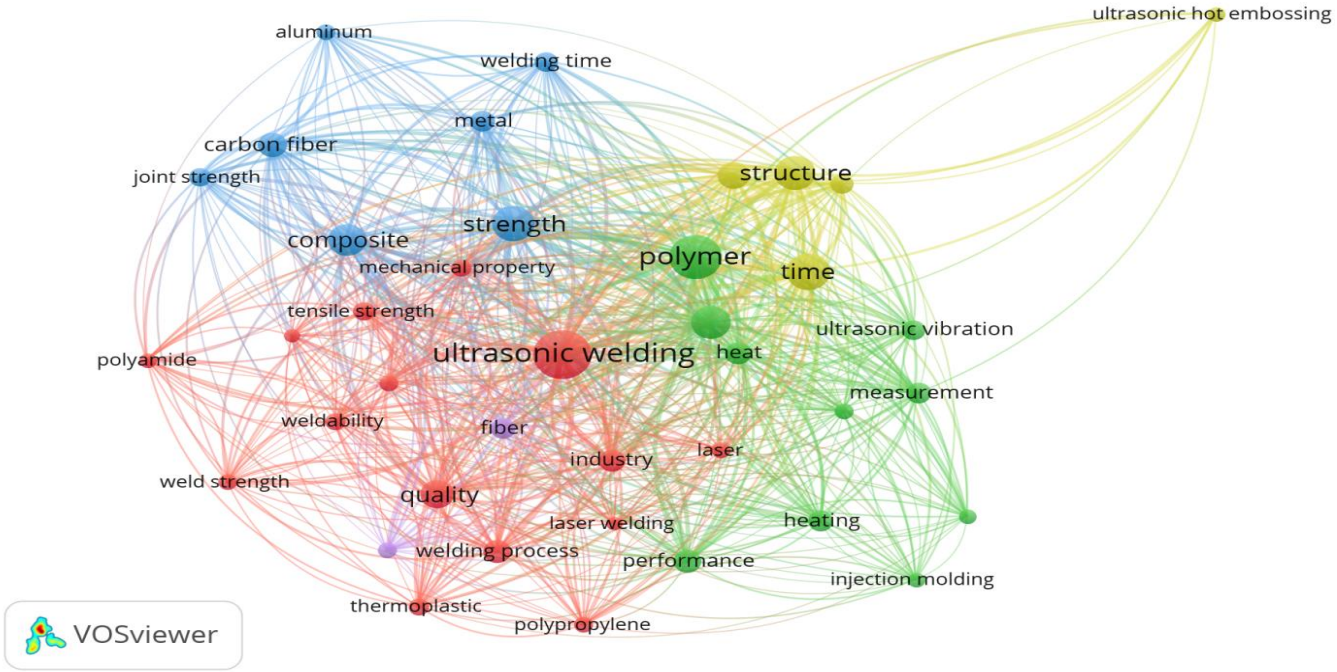


**Fig. 3 Bibliographic relational map analysis for the keyword "ultrasonic welding of polymer" (database source: www.webofknowledge.com)**

It is evident from Fig. 4 that the ultrasonic welding covered the wide spectrum of applicability with the investigations of the joint performances and various characterization techniques of polymeric materials. In the futures, studies in relation to ultrasonic welding of polymeric material may be explored to the investigations of the welding time, carbon fibre reinforcement, polymeric composites, dissimilar materials, high-performance engineering polymer like; polyamide, polyether ether ketone (PEEK), weldability of dissimilar polymers, ultrasonic hot embossing, ultrasonic vibration, etc. for the better applicability in various sectors such as; automobile, aerospace, industrial, marine, biomedical engineering, etc.

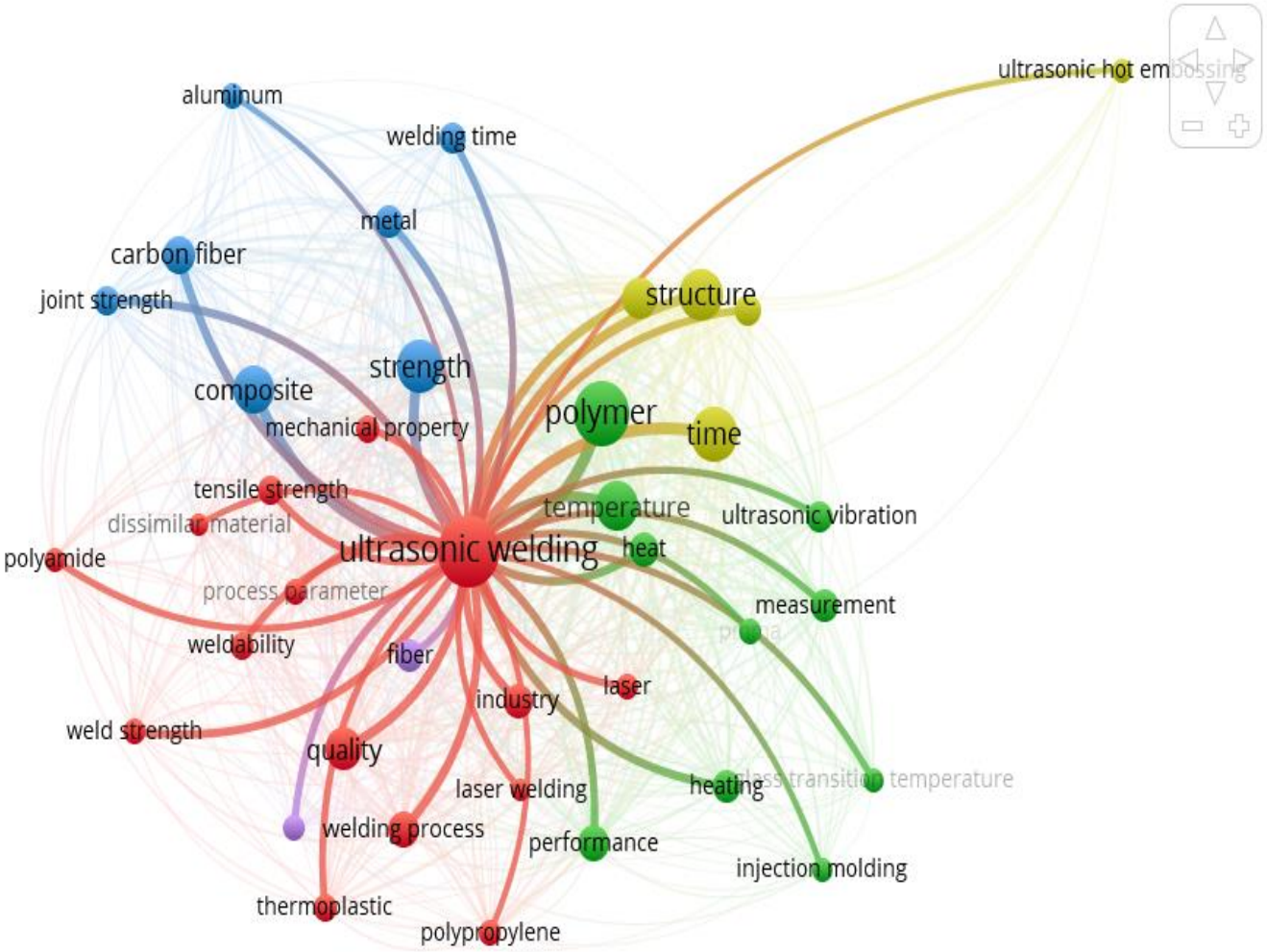


**Fig 4. Bibliographic map based gap analysis for ultrasonic welding of polymers**

## IV. Laser welding

However, the laser welding process has been considered a costly process due to its high equipment cost, but the laser welding process gives high outputs in welding performances. Using the web of science database for the keyword "laser welding of polymer," a total of 417 studies have been reported, which is larger as compared to the friction stir welding as well as ultrasonic welding. Fig. 5 shows the bibliographic map-based analysis for laser welding of polymers. The previous studies have been mostly reported for the investigations of the laser transmission welding of investigations of an optical property, carbon nanotubes, polypropylene, polycarbonate, process parameter investigations, polyethylene, polyamides, composite materials, etc.

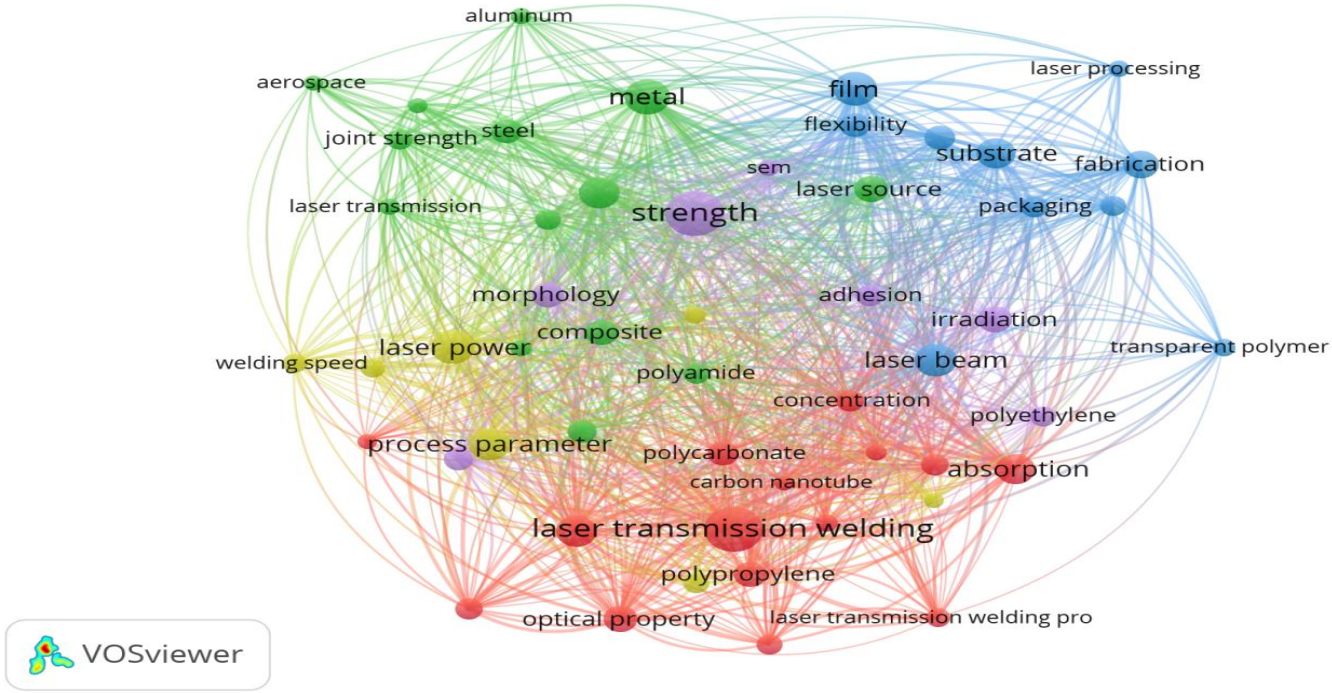


**Fig. 5 Bibliographic relational map analysis for keyword "laser welding of polymer" (database source: www.webofknowledge.com)**

Fig. 6 shows the bibliographic map based gap analysis for laser welding of polymers. It is evident from Fig. 6 that the futuristic studies may be explored for the laser welding of polymeric materials with investigations of the aerospace applications, laser processing, flexibility, industrial applications, laser powder, dissimilar materials, laser transmission, laser source, laser beam, transparent materials, packaging applications, irradiation, adhesion, morphology, etc.

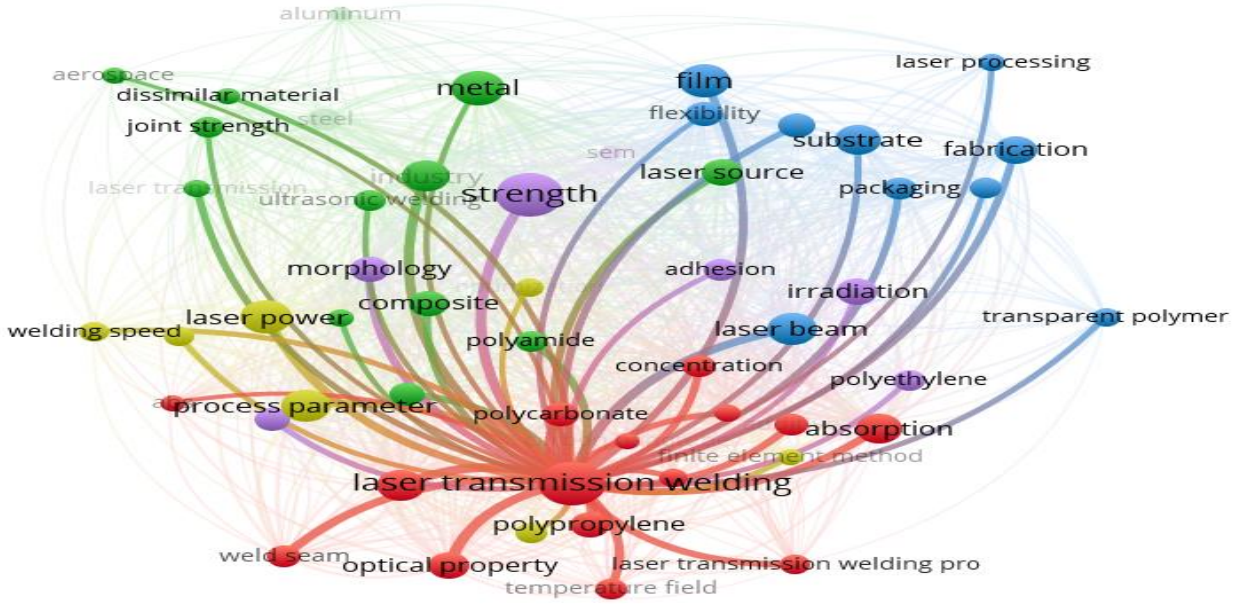


**Fig 6. Bibliographic map based gap analysis for laser welding of polymers**

## V. Resistance welding

Resistance welding is one of the solid-state welding processes that offer the joining of similar and dissimilar materials by applying the pressure and current between the joints' interfaces. The resistance welding eliminates the use of the external tooling and setup cost, which minimizes the cost of the welded product. A total of 228 studies have been reported by putting the keyword "resistance welding of polymer" on the web of science database. Fig. 7 shows the Bibliographic relational map analysis for the keyword "resistance welding of the polymer." The previous studies have been reported mostly for resistance welding of polymeric materials with investigations of the adhesive, carbon fiber reinforced polymer (CFRP), laser, microstructures, fibers, heat, performances, microstructures, composites, etc.

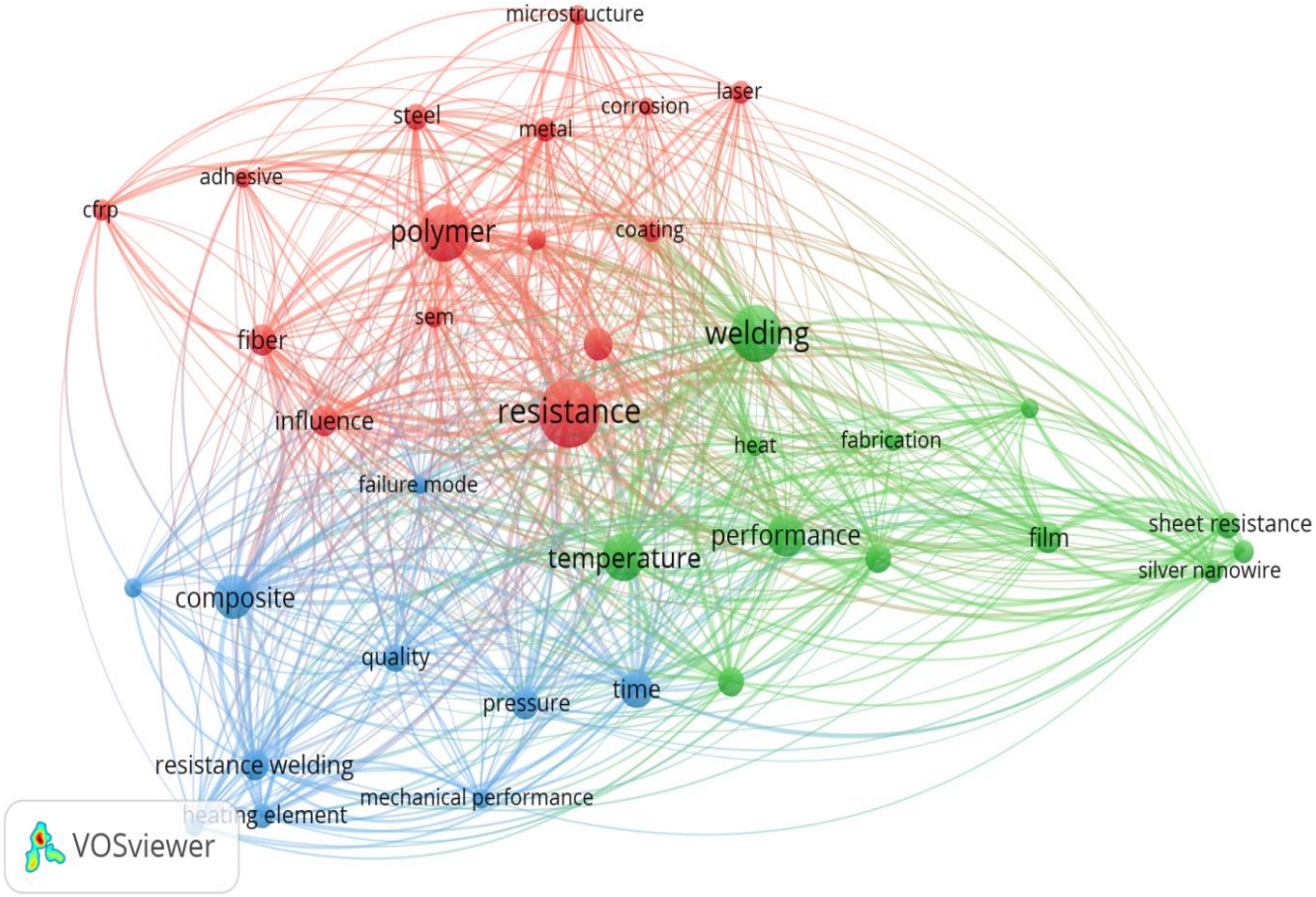


**Fig. 7 Bibliographic relational map analysis for the keyword "resistance welding of polymer" (database source: www.webofknowledge.com)**

Fig. 8 shows the bibliographic map based gap analysis for resistance welding of polymers. It is evident from Fig. 8 that there is a number of investigations may be carried out as future research work. The studies may be explored for the resistance welding of polymeric materials with investigations of the sheet resistance, using silver nanowire, maintaining the electric conductivity of polymeric composites, the heating element of resistance welding setup, mechanical performance, pressure, time, film materials, quality, failure mode analysis, heat, etc.

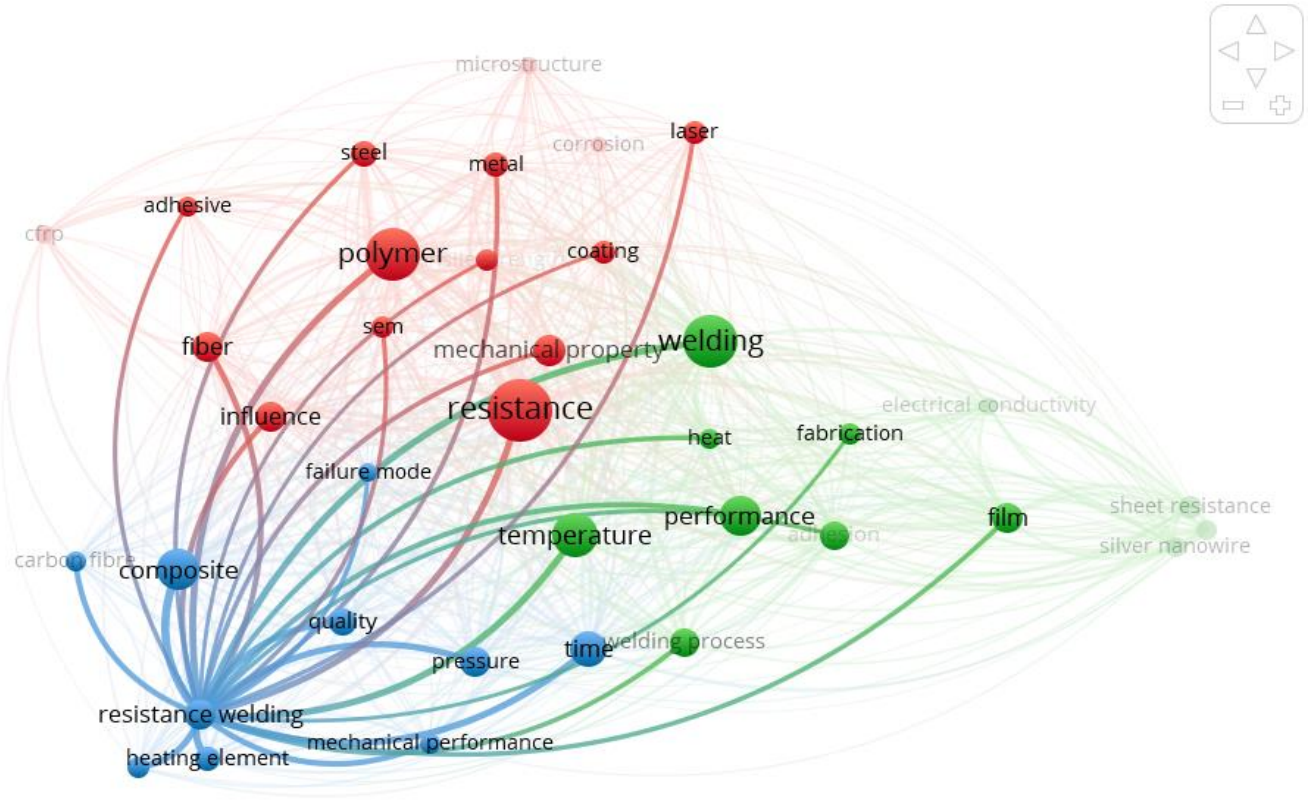


**Fig 8. Bibliographic map based gap analysis for resistance welding of polymers**

## VI. Conclusions

Some of the conclusions have been drawn from the study of solid-state welding process for polymeric materials;

- In the future, studies may be explored for the friction stir welding of polymeric materials with investigations of the joint strength, melt flow behavior, dissimilar materials joining, materials flow, polycarbonate sheet joining, polyamide joining, reinforcement of aluminum, and other metal
- In the futures, studies in relation to ultrasonic welding of polymeric material may be explored to the investigations of the welding time, carbon fibre reinforcement, polymeric composites, dissimilar materials, high-performance engineering polymer like; polyamide, polyether ether ketone (PEEK), weldability of dissimilar polymers, ultrasonic hot embossing, ultrasonic vibration etc. for the better applicability in various sectors such as; automobile, aerospace, industrial, marine, biomedical engineering etc.
- The studies may be explored for the resistance welding of polymeric materials with investigations of the sheet resistance, using silver nanowire, maintaining the electric conductivity of polymeric composites, the heating element of resistance welding setup, mechanical performance, pressure, time, film materials, quality, failure mode analysis, heat etc.

## Acknowledgement

The authors are highly thankful to University Center for Research and Development, Chandigarh University, for technical assistance.

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