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Review and Opportunities for Thermal Examination Approaches Used to Investigate the Thermal Properties of Composite Compounds

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Abstract

The use of thermal examination approach to assess the thermal quality of energy materials in "China" is concisely described. They are often used to calculate thermal stability, compatibility, and thermophysical constants, as well as to study thermal breakdown kinetics, causes, and interactions. Furthermore, a few studies focused on creativity or advancement, such as analyzing the mechanisms of topochemical reactions, assessing condensed-phase reaction kinetics by tracking the change in functional groups through Thermo-infrared spectroscopy, and assessing gas-formation reaction kinetics using Thermo-mass or Thermo-infrared spectrometry. A quick summary of how thermal analysis methods are used in China to assess the thermal characteristics of energy materials is provided. They are commonly used to examine the kinetics, mechanism, and interaction of thermal breakdown as well as to determine thermal stability, compatibility, and thermophysical constants. The thermal characteristics of energetic materials are thought to be the most crucial since they are directly linked to their safety throughout manufacture, transit, storage, and usage. A quick, easy, and efficient way to determine the thermal characteristics of energetic materials is to use thermal analysis tools. The current study summarizes and discusses the relationships between thermal properties and mechanical or combustion performance, the TX and HX phase diagrams, life expectancy and "low-temperature viscosity" predictions, and the "low-temperature thermal behaviour" of liquid energetic materials. Recommendations for future thermal experiments into composite materials are also given.

Keywords: Thermal property, composite, phase diagram, thermo mechanical examination, composite compound.

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INTRODUCTION

Thermal examination approach is said to have begun as a scientific experiment in the delayed nineteenth and start twentieth century. However, until the 1940s, the two most used thermal-analysis processes, differential thermal examination (DTE) and thermo gravimetric examination (TG), were mostly employed on inorganic materials such as clay and minerals. Thermal analysis of polymers was first reported in the late 1940s. Around the 1960s, thermal analysis technology evolved rapidly. Following the 1980s, several new thermal examination approaches emerged, including differential scanning calorimetry (DSC), thermo mechanical examination (TME), and dynamic thermo mechanical examination (DME). This was assumed to be directly governed to the fast growth of materials science. Additionally, available thermal examination tools became accessible during that time.

The thermal attributes of energizing materials, which are strongly connected to their suitability during manufacture, transit, repository, and usage, are perceive as the most significant characteristics of composite materials. Thermal examination methods make it possible to determine the thermal characteristics of composite materials quickly, conveniently, and effectively. In the beginning of 1960s, thermal examination approaches, particularly “DTE, TG, DTG, and DSC”, were frequently utilized to assess the thermal properties of energetic compounds such as “RDX and HMX”. In the mid-1960s, the “Xi'an Modern Chemistry Research Institute” began using DTA equipment to explore the thermal characteristics of composite materials, just 5 or 6 years after worldwide endeavours. Following that, MCRI made significant advances in the investigation of thermal characteristics of energetic materials using thermal examination approach. In 1990s, the use of thermal examination tools to characterize composite materials has received a lot of attention, with some new results. Every year, MCRI publishes a significant number of high-quality publications in renowned journals both at national and international, as well as many books, including "Thermal Analyses for Composite Materials" [1-3].

The goal of this study is to give a brief outcome of the use of thermal examination methods in the investigation of thermal characteristics of energy materials in China. A possible route for coming growth is offered, as well as some new application possibilities.

RESEARCH FOR COMMON APPLICATIONS

Thermal Stability and Reliability Evaluation

Thermal endurance and chemical adaptability are major thermal characteristics for energy materials. They are commonly assessed by detecting thermal deterioration. Chemical responses and interplay among constituents. The primary characteristics of energetic material breakdown are heat and gas release. Thermal analysis technologies and DSC are employing to assess thermal impacts in temperature-controlled operations, whereas TG can determine mass losses after gas release. Due of this, the initial application of thermal assessment methods in the study of energetic materials was to assess their thermal endurance and adjustability.

The two DSC and DTE are efficient in assessing the thermal stabilities, particularly for materials that have a thermal impact during decomposition but do not release gases or only emit minor quantities of gases. Furthermore, the tiny sample sizes required for thermal studies provide further advantages in terms of safety and speed.

In 1968, the “Honeywell Company of the United States” suggested DTE to analyze the camaraderie of energetic materials [4]. This assessment approach is currently extensively utilized in “China” and overseas, and it has also been codified as a national military standard [5-6]. Furthermore, the peak temperature or temperature differential of the exothermic peak recorded by DSC or DTA are frequently used to assess thermal stability or compatibility, however they are very dependent on the test circumstances. Although some test conditions are described in the standards, they may not be thorough due to sample diversity and complexity. As a result, DSC or DTA-based test standards are presented as unsuitable as the final foundation for evaluating compatibility [7]. Many works now evaluate compatibility using only DSC or DTA tests, which is clearly incorrect.

Determination of Thermal Physical Constants

The majority thermodynamic variables or thermophysical parameters of energized materials, such as a certain heat capacity, rate of expansion due to heat, heat transfer coefficient, melting temperature, and glass transition point, provide the foundation for practical applications, research in theory, and vibrant material selection. Therefore, it is very important to determine these factors. Methods for estimating propellant and explosive parameters have been established based on composite material properties.DSC stands for “continuous specific heat capacity”; TMA for “linear expansion coefficient”; DSC for “thermal conductivity”;[1]. The majority of these procedures have previously been defined as “national military standards” [8-12].

Regarding these, the DSC technique to determine the the heat transfer of tiny cylinder samples is a quick approach that involves connecting a device and produced by us to compensated differential scanning calorimeter [1,13-14].

Examination of Plasticizer Migration

The diffusion of synthetic plasticizers just like “nitroglycerin” in the propulsion to the coating layer, as well as the migration of an inert plasticizer, are the primary reasons of changes in ballistic performance and flame loss. For some propellants, the coating may be retarded, debonded, or fractured. As a result, it is critical to develop a technique for assessing plasticizer migration in coatings in order to determine migration kinetics and evaluate plasticizer migration processes in solid propellants.

Polarography, chromatography, weighing, and infrared spectroscopy are among of the methods used to investigate NG movement. However, these approaches have several drawbacks, such as long test times and high sample sizes. Furthermore, they only yielded the average NG content in the coating, making them unsuitable for analyzing plasticizer dispersion, which limits the research of migration mechanisms. We developed a microanalysis technique for determining NG migration in the coating via TG-DTG. It offers several advantages, including simplicity, speed, accuracy, and microsampling [15]. The obtained consequence can show the migration activities as well as forecast the service life [16-18].

NUMEROUS USES IN THE STUDY OF THERMAL FAILURE

Different Non-Isothermal Kinetic Equations Application

Thermal method of evaluation offers the advantages of being rapid, accurate, requiring fewer samples, safe, and dependable; in particular, it may be used to precisely quantify the thermal breakdown activities of energetic materials. As a result, during the 1950s to 1960s, research on thermal breakdown of energetic materials using thermal examination technology has progressed rapidly.

In the 1980s, we devised a non-isothermal kinetic equation, known as the DTA characteristic temperature equation, based on DTA's characteristic temperature, and effectively used it to analyze and assess the compatibility of several composite materials [19,20]. As a result, the non-isothermal kinetic approach was widely adopted for the study of thermal breakdown of energetic materials in China, particularly at MCRI, where researchers published several publications in relevant journals both at the national and international level [3]. Additionally, a book named "thermal analysis kinetics" was published [2]. However, the Kissinger equation and the Ozawa equation remain the most used equations in thermal kinetics study. Nonetheless, additional formulae, such as the Coats-Redfern equation, are employed to calculate the decomposed kinetic process function [1].

Constant Temperature Thermal Examination Approaches

Exothermic decomposition and mass loss only happen after melting in liquid reactions produced by non-isothermal DSC collapse of composite materials with melting points higher than room temperature. Investigating their solid breakdown processes using a planned heating approach is quite challenging. Phase transitions are widely acknowledged to have a major influence on the kinetics of decomposition reactions. Studying storage stability, compatibility with composite materials, and the effect of particle size on nano material qualities all depend on thermal breakdown kinetics at temperatures below solid-liquid phase transition (melting) or solid-solid phase transition.

The isothermal TG method is useful for studying the thermal breakdown kinetics of certain chemicals and combinations in solid states. Here are the steps in the action: Gather time-to-value data on isothermal TG mass loss, represented as a percentage α, which indicates the conversion rate or reaction depth. Choose the kinetic explanation variable g(α) that seems most likely. To get the rate constant k, attenuate on the linear relationship $g(\alpha) = k \bullet t$. The Arrhenius equation is used for determining the pre exponential factor A and perceived activation power Ea for k values at different temperatures. This approach yields the kinetic parameters Ea and A, as well as the mechanism function g(α). We have authored multiple articles on the subject [1, 21, 22]. This approach is recommended for scholars interested in studying the disintegration of solids at low temperatures.

Kinetics of Thermo-Infrared and Thermo-Mass Spectrum Gas Production

In addition to the thermal examination data, the non-isothermal kinetic technique may utilize to evaluate the dependent curves of infrared absorption [23]. So, the kinetic criterion of the gas formation process is determined. They are known as "thermo-infrared" ("TIR") and "thermo-mass spectrum" ("TMS") gas formation kinetics [1, 25].

Since the thermal impacts or loss of mass noticed by the thermal examination equipment are induced by the overall response to various gas geological formations, the kinetic variables of gas-formation processes using "TIR or TMS" are more analogous to basic reaction kinetics than obvious kinetic variables, such as evident activation power or global energy of activation. As a result, researching gas formation kinetics is a more realistic approach to understanding the breakdown process. It is expected that such a research will attract increased attention [28, 29].

Study on Interactions

Analysing the system's compatibility entails investigating the interactions between various system components at storage or slightly elevated temperatures. This interaction process might involve a variety of interactions, such as condensed phase reactions, gas-condensed phase reactions, and gas-gas phase reactions. Furthermore, in many circumstances, mixed systems decompose in phases, with the first and subsequent reactions occurring accordingly. DSC and TG, particularly high-pressure DSC and once thermal analysis, are well suited for studying these interactions. A thermal analysis technique has been utilized extensively to study the thermal breakdown behaviours and interactions of energetic materials. The book "Thermal Analyses for Energetic Materials" has two chapters that are specifically dedicated to the connections of multiple parts of active substances [1].

Investigation of Decomposition Mechanism

Aside from reaching thermal variables, the mechanism of reactions can be conjecture through executing examinations under various circumstances (including the investigate the environment, pressure in the environment), using at once thermal examination criterion such as “FTIR, MS, and GC”, and employing the procedure of "identification of sudden stop sampling".

Several instances of mechanisms assessment by altering the trial procedures are shown below: Varying the heating rate determines whether there is "decomposition melting" or The "melting decomposition" “process of solid materials during heating”; modifying the heating rates of DSC (DTA)-FTIR (MS) tests can forecast the temperature effect trend of competitive reaction. In addition, modifying environmental forces can solve the following issues: When there exists a significant quantity of volatilizing or sublimation during reactant breakdown, whether reactant contact occurs decomposition reaction engage in the secondary reaction. The secondary reaction, also known as the accelerated reaction, may be examined with varying carrier gas flow rates. As previously indicated, the breakdown pathways may be deduced by identifying elements of intermediates collected by "sudden stop sampling" technology and end products using XRD, FTIR, and other techniques. Furthermore, it is one of the most effective methods for revealing reaction processes by gas product analysis using DSC –FTIR linked simultaneous technology.

A great deal of research has been conducted in this topic at MCRI, many of which are ground-breaking, and a considerable counting of publications has published [30-42], with some instances of real-life uses available in the book "Thermal Analyses for Composite Materials".

Study on Topochemistry

Many solid crystals' breakdown reactions often begin at certain spots on the crystal that are within the unsaturated force field. These unusual spots are known as "nuclei" or "potential nuclei"[43]. The occurrence of nuclei is typically associated with crystal flaws like as lattice faults, dislocations, and fissures. Further the decomposition activity is understood as the "nucleation" of the nuclei followed by

"nuclear growth," that is, the degradation reaction begins in the local region of the crystal and develops from there. Thus, this breakdown process is known as "topochemistry" or "topochemical reaction" [44]. Various "nucleation" and "nuclear growth" methods can provide commonly used kinetic mechanism functions g(α).

Thermal evaluation methodologies demonstrate their utility in investigating "topochemical processes," as they allow for the convenient determination of whether solid state breakdown follows the "topochemistry" process [1,45]. It is currently demonstrated that the presence of "topochemistry" processes has a significant impact on thermal breakdown and several attributes of energetic materials, including thermal stability, compatibility, and storage life [1, 46-49]. As a result, the "topochemistry" method for synthesis energetic molecules is worthwhile to investigate, and we conducted extensive research in this area.

COMBUSTION PERFORMANCE RELATION INVESTIGATION

Equations Representing the Link Between Burning Rate and Pressure DSC Characteristic Values, Both Univariate and Bivariate

The ignition and explosion of explosive substances are complicated multiple stages activities that include chemical interactions between condensation and gaseous stage. They are distinguished by a great quantity of energy release, enormous and quick creation of gaseous products, high temperature, and pressure, and expeditious temperatures increase.

Hypothesised that in the combustion of solid propellants, gas-phase reactions occur considerably quicker than condensed-phase reactions, hence thermal breakdown of condensing stages is the rate-determining step. An empirical equation of a univariate relation for the link between combustion rates as well as pressure characteristic data was found [1]:

$$u = k_u[P\triangle H_d /\triangle T]^{1/2} = k_u[P\triangle S_d]^{½} \quad (1)$$

The equation is as follows: u = mm/s, P = Pa, △Hd = J·g-1, △T = Te-T0, ℃.

DSC trials include gradual temperature increases, hence △T represents the time necessary for the exothermic process.△Sd =△Hd/△T represents the heat release rate. The equation (1) is referred to as a "univariate equation" since it treats (P·△Sd) as a single variable [1, 50].

fortunately, due to the thermal evaluation instrument's stress limit (<7 MPa), equation (1) was not employed to build a propellant with a higher burning rate plateau. Equation (1) uses two independent variables (pressure P and heat release rate △Sd) to connect PDSC values with combustion rates at higher pressures. A new multivariate empirical solution has been created:

$$u = k_u \cdot P^m[\triangle H_d /\triangle T]^n = k_u \cdot P^m \cdot \triangle S_d{}^n \quad (2)$$

The constants m and n represent the contributions of pressure and heat release rate $\triangle S_d$ to the explosion rate.

Characteristic Parameter Equation of The Relationship Between the Kinetic Variables of Decomposing and Burns Rates

To learn more about the relation between the thermal degradation and ignition outcomes of composite resources, utilising the heat balance formula of steady state the combustion and the non-isothermal chemical kinetic formula of thermal decay of the propellant, the equation among burning rates and the The thermodynamics (T and Q) and kinetics (Ea, A, and g(α)) of disintegration were studied. Thus, the "r-PDSC equation" defining the link among multistage “thermal degradation properties” and combustion rate was suggested.

Issues That Need to Be Resolved in Order to Investigate the Connection Among Combustion Rate and Thermal Failure

A semi-empirical equation as the slope is influenced by propellant performance, despite theoretical calculations based on PDSC test results. The equation assumes that thermodynamic parameters like heat conductivity (λ_R) and CPR at constant pressure are independent of temperature and pressure, despite their close relationship [42]. Thermal decomposition not only produces energy for the combustion process, but it also offers necessary reactants, namely thermal breakdown gas products. Thus, knowing the breakdown products is critical for investigating thermal decomposition under combustion circumstances. The simultaneous techniques of thermal analysis and IR or MS give methodologies for analysing and identifying gaseous decomposition products at ambient pressure, which is useful for evaluating thermal decomposition processes. For reactions at high temperatures and pressures, Professor Brill et al. of the University of Delaware introduced the T-Jump/FTIR simultaneous approach, which might be used to detect gaseous products [45,46]. It has been employed in studies on the thermal breakdown of a variety of composite materials and combinations. The composition of gas products varies with temperature and pressure. A breakdown process has been postulated for high temperatures, high pressures, and rapid heating rates [47]. However, there has been minimal investigation into the link between thermal breakdown products and combustion performance.

For the growth of energised resources, it is considered that both the recognition of thermally decomposed products resulting from energised materials, particularly propellants, under simulated combustion situations and a review of the association among product structure and ignition outcomes are critical.

DMA APPLICATIONS IN ENERGETIC MATERIALS RESEARCH

Propeller's Viscoelasticity and The Way Its Constituent Parts Interact

Gun and solid rocket propellants, munitions may all be classified as polymer matrix composites. DMA (dynamic thermomechanical analysis) is a popular method for investigating the viscoelasticity of polymer S/M, which is directly connected to mechanical characteristics. It may be used to assess the characteristics of viscoelastic materials, like the temperature at which glass transitions occurs, the part of the movement and relaxation process, the crystalline makeup of polymers, and the interaction between molecules [1].

Through the use of the viscoelastic coefficient, vertical movement factor , “relaxation activation energy” Ea, and “loss tangent” tan δ derived from the original curve, the outcomes of solid fillers, plasticizing agents, and binding molecules on the viscoelastic and absolute mechanically features of catalysts and the connections among the different elements were addressed [41-44]. Changing the nitrogen concentration from 13.0% to 12.6% in NC decreased peak temperature and increased peak intensity of the tanδ on the β-transition of the DME temperature spectrum of double base propellants [32-34].

The “Williams, Landel and Ferry” formula and multi-frequency experiments were used to study the critical temperature (Tc) of mechanical characteristics for low-temperature propellants that are solid under combustion or releasing loads [32]. The crucial temperature is the lowest temperature at which solid propellant can preserve its impartiality after combustion or releasing.

Estimating Final Mechanical Characteristics from Dynamic Physical Testing Results

The ultimate mechanical qualities refer to the greatest tensile strength (σm). During tensile or compressive testing, the maximal compressive strength (σb), elongation (εm), and compressibility (εb) are obtained. Compressive or tensile testing are performed with a “constant strain rate”.

A connection was established among static mechanical and dynamic mechanical constant, as well as among stress relaxation, creep, and the final performances outcome in constant strain-rate experiment

(compressive and tensile test). Two equations representing the relationship between dynamic storage compliance and ultimate elongation or compressibility and the association among dynamic storage modulus and ultimate tensile strength or compressive strength were derived from these two interactions. The study computed the “tensile strength”, “compressive strength”, “elongation”, and compressibility of many solid propellants at varying loading speeds and temperatures. The results dem onstrated good agreement with the experimental data.

Unfortunately, a variety of variables might affect the precision of the tensile and compressive strength testing, which frequently results in low data repeatability and reproducibility. Numerous experiments are required to determine the optimal mechanical characteristics at various temperatures and loading rates. Based on a multi-frequency DMA spectrum, the aforementioned correlations provide prediction of the final mechanical qualities at any heating and loading. However, it should be noted that the dynamic module master curve received from the DMA test does not match exactly with the “stress-strain master curve” obtained from the ultimate mechanical test in either the high- or low-temperature range, indicating a discrepancy between the measured and calculated data. It is suggested that this is because of the limitations of the WLF equation, hence further research is thought to be necessary in order to forecast the mechanical characteristics.

DMA's Potential for Estimating the Useful Life of Energy Materials

Physical aging is the term used to describe how temperature and time affect a polymer's mechanical characteristics, such as stress and strain. If these alterations surpass the material's strength, the materials will fracture or distort and eventually collapse catastrophically. The study of how physical aging affects material characteristics and how to forecast a person's physical aging life has long drawn interest and produced a substantial body of research.

However, it is thought that dynamic mechanical characteristics are more accurate in describing physical aging and predicting physical aging life than ultimate mechanical measures like tensile strength, elongation, and compressibility. The dynamic mechanical characteristics may be obtained fast and precisely by using DMA experiments. The formula for defining the aging rate (μ) of polymers was provided by Brennan, Venditetti , and Smith.

$$\mu = E'/E'_0 \quad (3)$$

$$\mu = d(E'/E'_0)/d\log T \quad (4)$$

The storage modulus at the reference temperature Ts is denoted by E′o, whereas the storage modulus at the aging temperature T is represented by E′.

Activation energy (also known as molecular relaxation activation energy) Ea may be determined from changes in dynamic mechanical properties since dynamic mechanical characteristics are evaluated in DMA experiments at predetermined temperatures. Under "Point-Slope Method" equation, the mathematical model is identified. One might readily predict the aging life using it. Analyzing the dynamic modulus variation law or compliance master curve simultaneously allows one to determine the failure criteria of dynamic mechanical characteristics and comprehend the failure cause. explosives such as PBX (plastic bound explosives), solid rocket propellant, and others composite materials with a high content of solid fillers are classified as viscoelastic polymer composites. The mechanical qualities would deteriorate and could even be destroyed due to interactions and physical aging. It is reasonable to anticipate the service life of energy polymer systems based on physical aging, which is why physical aging should be considered a primary failure mode. Below are some instances of how solid propellant aging life may be predicted using DMA.

PHASE TRANSITION AND PHASE CURVE

Solid-Solid Stage Transition

Phase transitions, including those between solids and liquids (such as melting and crystallization) and between supercooled states or high elastic states and glass states, are significant considerations in the production, storage, and use of composite materials. You should steer clear of some phase transitions. At ambient temperature, for instance, there should be restrictions on the crystal phase transitions between ammonium nitrate types III and IV. In another example, at temperature ~~A~~156 °C, β-HMX will convert to unstable δ-HMX with a loss in density and an increase in volume (5.8-9.1%), potentially leading to the dissolution of the HMX-based charge body. Therefore, the operating temperature for the manufacturing, storage, condition should not be higher than 156 °C.

Considering the associated thermal effects, DSC and DTA are regarded as useful methods to study phase transitions. Ammonium nitrate (AN)'s five crystal forms have undergone changes, and our analysis of these changes using DSC has shown that moisture content, purity, and thermal history all have a significant impact on these changes [1]. In order to stop AN from crystallizing, we have also investigated a number of stabilizers. For type III-AN, potassium dinitramide (KDN) is an effective stabilizer [1,34,].

Kinetics of Liquid-Solid Stage Change “Crystallization of The Melts

An important class of energetic materials is melt-cast explosives. The process of casting is really a combination of liquid (or melt) solidification and solidification (or crystallization) of solid (or crystalline). The process of solidification and formation requires cooling crystallization of the molten energetic material used as a liquid-phase carrier. Product quality is intimately linked to the crystallization process. For this reason, it is very controlling the crystallization activity for the melt-cast explosive requires an understanding of crystallization kinetics.

This suggests that “HMX and RDX” may function as nucleating agents, heat dissipation agents, and inhibitors of supercooling. Because of this, all of the melt-cast explosives under examination had nitramine (HMX, RDX) concentrations of 75% (mass ratio) [1].

Glass Transition

Non-equilibrium states include the supercooled state and the glass state. Certain energetic materials in the supercooled state may experience "hot crystallization," or the phenomena of crystallization while heating, whereas other materials may transition into a glass state. When storing and using, one should steer clear of both the glass transition and heated crystallization. DSC at low temperatures is frequently used to investigate these phenomena.

The primary ingredients of liquid gun propellant (LGP), which is a supercooled solution system, are “hydroxylamine nitrate”, “triethanolamine nitrate”, and H2O. Additionally, the solution's concentration range where Tg possesses a "colligative property" was identified based on this [1]. The planning and implementation of LGP are encouraged by these study findings.

A crucial physical characteristic of liquids is their viscosity. Though it might be challenging to quantify viscosity at low temperatures, viscosity and temperature are strongly connected. This modification is based on the belief that accurate predictions of low-temperature liquid viscosity are possible. Thus, the low-temperature viscosity prediction technique for liquid cannon propellant that has been supercooled is established .

Diagrams of Binary and Ternary Phases

Low vulnerability (LOVA) explosives make up a large portion of low eutectic intermolecular bombs. Based on the matching liquid-solid phase diagrams, one may determine the mass (or molar) ratio of eutectic components. Liquid-solid phase diagrams illustrate the correlations between component contents (X), liquefying temperatures T, and freezing temperatures T. The TX phase diagrams are often created by monitoring the melting or solidification temperatures during heating of systems with varying compositions.

The benefits of DSC include the ability to estimate for mixed systems quickly and accurately, as well as the absence of supercooling during experiments.

The process of creating HX phase diagrams using DSC is comparatively quick and easy compared to creating TX phase diagrams. Furthermore, only HX phase diagrams rather than TX ones may be obtained for chemicals that break down during melting, like "TNTAU, HMX, RDX, NQ, and NTO". It should be mentioned that an experimental measurement of their actual melting point is not possible because of the inevitable breakdown that occurs throughout the melting process. This melting heat may be determined, meanwhile, by envision a binary HX phase diagram of these kinds of compounds and a molecule that undergoes a typical melting process [1]. According to this, only HX phase curve can be created for volatile energetic compounds like molten TNAZ using high pressure DSC, which may prevent volatilization and conversion. These approaches have also been used to the investigation of various thermal characteristics of energetic explosives [1].

CONCLUSION

A common method for assessing the thermal characteristics of energetic materials is thermal analysis technology. This review provides an overview of the work done at the Xi'an Modern Chemistry Research Institute. Many studies have been carried out in the last few decades, including the thermal assessments of energetic materials, the creation of test protocols, and the use of novel thermal analysis tools. Furthermore, a large number of scholarly works—more than 100 of which are SCI-indexed—have been published on.

Still, there are still some problems that need to be resolved. For instance, it has been demonstrated that it is feasible to forecast the final mechanical characteristics and service life from the dynamic mechanical properties; nevertheless, further investigating this further is recommended, as well as encouraging the use of these techniques. But when thermal analysis technologies advanced, particularly the simultaneous methods of merging thermal analysis with other methods of analysis, new avenues for study were created and insights into the behaviours of energetic materials were fostered.

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