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New Generation of Non-Leaded Free Cutting Steels: Characterization and Machinability

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Abstract

The growing sensitivity of regulations regarding the use of heavy metals increasingly demands the use of new lead-free steels, whose development has become a strategic priority for the entire steel industry. Despite strong interest, the development of alternatives to leaded free-cutting steels has so far been limited by economic reasons related to the high cost of research, development, and commercialization. This thesis aims to characterize the machinability and the mechanical/metallurgical properties of a new generation of bismuth-containing free-cutting steels (11SMnBi30), comparing their performance with that of the alloys currently most used in the industry (11SMn30 and 11SMnPb30). The research was structured in three main phases: the first phase involved the mechanical/metallurgical characterization of the three alloys under investigation through tensile, hardness, and impact tests at room temperature, followed by in-depth metallographic and inclusion content analyses (shape, number, and distribution of inclusions). The second part of the project was dedicated to lathe cutting tests to evaluate cutting forces, absorbed power, tool wear, and surface finish, varying tools and lubrication conditions. The third and final phase allowed the determination of statistically significant differences between the three steels through ANOVA (Analysis of Variance) of the data obtained during experimentation. The results clearly showed that bismuth-containing free-cutting steels are a good alternative to traditional ones, particularly with reference to the high cutting speeds to which this category of steels is specifically dedicated. The statistical approach used to process the large amount of data also made it possible to determine the limits and best practices for the use of this new class of steels.

Keywords: Lead-free steels; bismuth steels; turing machinability.

Abstract in lingua italiana

La crescente sensibilità delle normative rispetto all'uso di metalli pesanti impone in modo sempre più urgente l'utilizzo di nuovi acciai privi di piombo, il cui sviluppo è diventato una priorità strategica per l'intera industria siderurgica. Nonostante il forte interesse, lo sviluppo di leghe alternative agli acciai automatici contenenti piombo è stato finora limitato da ragioni economiche legate all'alto costo di ricerca, sviluppo e commercializzazione. Il presente lavoro di tesi ha l'obiettivo di caratterizzare la lavorabilità alle macchine utensili e le proprietà meccaniche/metallurgiche di una nuova generazione di acciai automatici al bismuto (11SMnBi30), confrontando le loro prestazioni a quelle delle leghe attualmente più utilizzate a livello industriale (11SMn30 e 11SMnPb30). La ricerca è stata articolata in tre fasi principali: la prima ha previsto la caratterizzazione meccanica/metallurgica delle tre leghe oggetto d'indagine tramite prove di trazione, durezza e resilienza a temperatura ambiente, seguite da approfondite analisi metallografiche e del contenuto inclusionale (forma, numerosità e distribuzione delle inclusioni). La seconda parte del progetto è stata dedicata alle prove di taglio al tornio, al fine di valutare le forze di taglio, la potenza assorbita, l'usura dell'utensile e la finitura superficiale al variare degli utensili e delle condizioni di lubrificazione. La terza, ed ultima, fase ha invece consentito di determinare le differenze statisticamente significative tra i tre acciai tramite analisi ANOVA (Analisi della Varianza) dei dati ottenuti durante la sperimentazione. I risultati hanno evidenziato chiaramente che gli acciai automatici al bismuto costituiscono una buona alternativa a quelli tradizionali, con particolare riferimento alle alte velocità di taglio a cui questa categoria di acciai è specificamente dedicata. L'approccio statistico utilizzato per elaborare la grande mole di dati ha altresì permesso di determinare i limiti e le modalità di impiego maggiormente corrette per questa nuova classe di acciai.

Parole chiave: Acciai senza piombo; acciai al bismuto; lavorabilità alla tornitura.

1 | Introduction

The objective of this thesis is to study the machinability of different types of free cutting steels, specifically 11SMn30, 11SMnPb30, and 11SMnBi30. Machinability is a fundamental aspect of chip removal manufacturing processes such as turning, drilling, and milling. Efficient and quick machining not only improves productivity but also reduces manufacturing costs, making it an essential consideration for industrial applications. Free cutting steels are engineered for excellent machinability, allowing faster and more efficient manufacturing. Sulfur and lead are common components in these steels, which make them perform better during high speed machining. Since lead can reduce friction and tool wear, it has historically been used extensively to improve machinability. However, the research for substitute alloying elements has been encouraged by worries about lead effects on the environment and human health.
Standard free cutting steel 11SMn30 is well-known for its high machinability because of its sulfur content that embrittles the material. 11SMnPb30 contains lead, which improves its machinability but also poses health and environmental hazards. 11SMnBi30 replaces lead with bismuth, an element that is quite comparable, with the goal of maintaining the benefits of machinability while resolving the issues associated with lead. A variety of mechanical tests, including tensile, impact, and hardness tests, as well as high-speed turning tests, will be used by the thesis in evaluating these steels. For assessing the performance of the steels, important factors such reaction forces, surface roughness, and chip formation will be evaluated and compared. This study aims to assess bismuth as a long-term substitute for lead in free-cutting steels while promoting sustainable manufacturing practices. The objective is to enable high-performance machining without environmental compromise, fostering the broader adoption of bismuth-containing steels as a viable alternative for high-speed applications.

1.1. Criteria for Machinability

In the contemporary industrial landscape characterized by mechanics, machinability assumes paramount importance in assessing overall performance within the realm of manufacturing processes like turning, drilling, and milling. Numerous variables influence the efficacy of operations. These manufacturing methodologies primarily involve chip removal, employing cutting tools like drills or specialized tools to exert force on the workpiece. Such force induces material deformation and eventual fracturing, leading to the formation of chips, Figure 1.1, Figure 1.2.

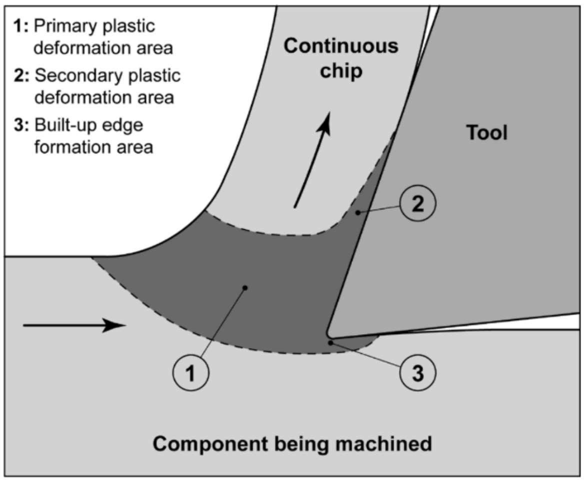


Figure 1.1: Continuous chip formation [1]

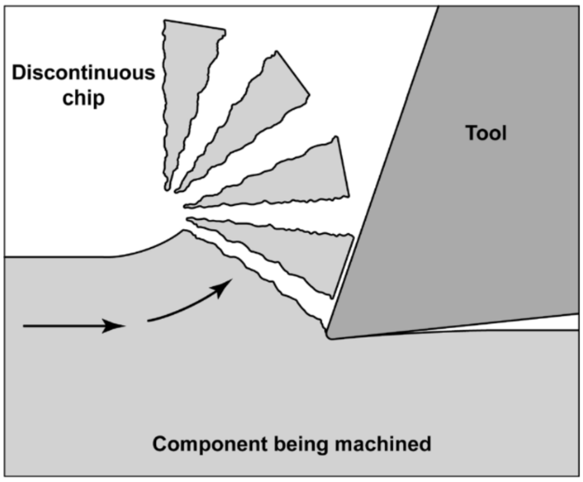


Figure 1.2: Discontinuous chip formation [1]

The most used factors to evaluate machinability are:

- Forces created in the process,
- Surface quality of the workpiece,
- Chip form,
- Tool life.

The importance of each single criteria might changed based on the needs of the manufacturing company. In industries the elongation of tool life is imperative to minimize the expenses associated with tool or insert replacement. Ensuring efficient chip breaking and evacuation is vital for achieving high levels of automation, particularly in processes like drilling. Conversely, stringent control over forces is necessary to mitigate the risk of surface defects ranging from elevated values and oscillations. The surface quality of the final workpiece serves as a tangible manifestation of overall product quality assurance, obtaining a high quality directly while turning avoids further costly finishing operations. Several more factors that can be taken into account are: friction coefficient, cutting temperatures and build up layer formation [3].

1.2. Overview of Free Cutting Steels

In the pursuit of efficiency within mass production, marked by extensive automation and advancements in industrial practices, there is a significant emphasis on minimizing cycling times. Given that the machinability of a workpiece often constitutes approximately half of the total manufacturing expenses, the utilization of free cutting steels emerges as advantageous. These steels, characterized by their formulation tailored for proficient high-speed machining operations, offer notable benefits within modern industrial contexts [1] [3]. This involves:

- Sufficient surface quality,
- Ensuring that chips break easily during machining,
- Limiting built-up edge formation,
- Reducing tool wear, nicks, heat micro-cracks, and cratering.

Additionally, free cutting steels present a self-lubricating effect when in contact with the cutting tools. They share similarities with structural steels but are distinguished by the presence of sulfur and/or lead, added during manufacturing to improve machinability. Free cutting steels usually exhibit lower cutting forces, reduced tool wear, and limited built-up edge compared to traditional steels, leading to improved dimensional tolerances and surface finish of machined parts. Optimal machinability occurs when inclusions are small, round, and evenly distributed throughout the metallic mass. These steels find extensive use in manufacturing screws, bolts, nuts, metal fittings, small automotive components, along with various mechanical parts.

In current production, these steels have sulfur content ranging from approximately 0.30 to

0.40% and manganese content around 1 to 1.5% facilitate the formation of elongated manganese sulphides (MnS) inclusions, aligning in the direction of maximum plastic strain to prevent excessive brittleness. Another important alloying element is lead, an element used to improve machinability, present in concentrations between 0.20 to 0.35%. Despite being insoluble in steel, lead forms small, round discontinuities. Both manganese sulphide and lead inclusions aid chip breakage and provide self-lubrication at the tool/part interface. Lead carries these advantages but brings many problem to the table that are now being looked upon.

The chemical composition of these free cutting steels is denoted by their designation, which corresponds to the nominal carbon percentage multiplied by 100, with letters indicating the presence of chemical elements such as sulfur, manganese, and lead, in decreasing order of concentration. Despite functioning as general-purpose structural steels, their composition emphasizes elements conducive to enhanced machinability, such as sulfur and lead, alongside additions like phosphorus, selenium, tellurium, antimony, calcium, bismuth, or tin. However, it is notable that their high sulfur and phosphorus contents compromise their weldability in comparison to carbon (structural) steels.

Considering that material properties are predominantly dictated by the intended application, modifications to grain boundaries, slag content, cold working, or chemical composition are often limited. Consequently, the optimization of machining properties is best achieved through the utilization of free cutting steels. These steels, categorized based on their heat treatment requirements, encompass various types:

- Low carbon free cutting steels (mild steels), which do not undergo heat treatment post-machining (e.g. 11SMn30, 11SMnPb30, 11SMnPbTe30).
- Free cutting case carburising steels with a low carbon and partially low sulfur content. As indicated, these steels are employed for case hardening post-machining (e.g., 10S20, C15Pb, 16MnCrPb5, 16MnCrS5Pb).
- Free cutting carbon (quench and tempering) steels featuring carbon contents surpassing 0.3%, the majority of steels within this category maintain low sulfur levels to mitigate significant impacts on material strength and toughness (e.g., 35S20, C35Pb, C45Pb).

1.2.1. Leaded Steels

Lead (Pb) is utilized in steel primarily to enhance machinability without significantly affecting mechanical properties. Lead can be present as an alloy element between 0,15%

and 0,35% of the mass of the steel [4]. It has a face-centered cubic crystal structure, a density of 11.34 g/cm^3, a melting point of 327.5°C, and a boiling point of 1749°C. Despite being almost insoluble in steel, Pb, when added, remains dispersed as submicroscopic metallic inclusions during solidification. Its presence helps in reducing friction during machining, thus increasing machinability [5].

In order to add it to the steel, Pb comes available in various forms such as cored wire or pellets, and its distribution is carefully controlled to prevent segregation, as it is a heavy metal that can sink to the bottom. Lead vapor generation during addition necessitates ventilation to maintain safe atmospheric concentrations. The effects of Pb on steel properties, such as reducing transverse ductility in annealed steels and impairing high-temperature impact strength, are generally tolerable for the general field they will be used. However, it promotes the formation of smooth surface spangles during galvanization, and excess Pb settles as an immiscible liquid in galvanizing baths.

Pb-bearing steels do not experience significant changes in heat treatment processes; nevertheless, because of the insulating nature of the scale that forms, they need more aggressive quenching. In the production of precision items, such as ABS brakes, dental instruments, and instrument panels, where toughness and ease of machining are critical, its beneficial effects on cutting speeds and tool life make it important.

1.2.2. Sulfurized Steels

Sulfur (S) is an element present in steel primarily introduced through iron ore and coke fuel during steelmaking. Considered as an impurity and often reduced to low levels for standard use, steel destined for machining requires a minimum sulfur content to facilitate good chip formation. Various methods are employed to achieve low sulfur levels in steel, with desulfurization often performed at the hot metal stage to maximize cost benefits.

Sulfur is purposefully added again for resulfurization in the steelmaking processes; this usually takes the form of stick sulfur or cored wire. Compared to stick sulfur additions, cored wire injection systems provide more accurate composition control and cause less environmental pollution. Less frequently used are other resulfurizing agents such as iron sulfide and flowers of sulfur.

Sulfur presence in steel has several adverse effects, including the formation of undesirable sulfides, which can lead to granular weaknesses and cracks, reduced melting point and intergranular strength, and increased brittleness. Sulfur also affects weldability, corrosion resistance, and fatigue properties, making it crucial to control its content, especially in critical applications like arctic grade line pipe and ship plate [6]. To reduce the detrimental effects of sulphite inclusion, manganese (Mn) is always added. During the solidification process of steel, sulphide inclusions predominantly manifest as manganese sulphides (MnS). Notably, MnS inclusions exhibit a higher melting point of 1610°C and typically appear as primary idiomorphic crystals. Although present in most steel compositions, MnS inclusions also offer beneficial effects such as enhancing machinability and impeding grain growth. Given their pivotal role, extensive research endeavors have been dedicated to investigating the morphology and distribution of MnS inclusions due to their beneficial impact on the diverse properties of steel.

1.2.3. Bismuth Steels

Bismuth (Bi), a metallic element with an atomic number of 83, shares similarities with lead, appearing as a silver-white to shallow-yellow metal. Notably, it has a melting point of 271.3°C and a boiling point of 1560°C, similar to those of lead. Despite its resemblance to lead, bismuth offers a promising substitute in steel production. Where lead is commonly added at concentrations of 0.05–0.35%, bismuth is present only around 0,05%. This substitution is driven by concerns over the adverse environmental and health impacts associated with lead usage.

The analogous physical and chemical properties of bismuth to lead, together with its reduced macrosegregation tendencies, make it an appealing option for enhancing environmental sustainability and safeguarding human health. Similar to lead, bismuth remains insoluble in solid steel and tends to accumulate and precipitate at grain boundaries in fine spherical shapes. Moreover, bismuth's low melting point also plays a pivotal role in improving steel machinability like lead. By facilitating lubrication during cutting processes and preventing overheating, bismuth proves to be an effective and efficient additive.

With an estimated reserve of 330,000 tons, mostly concentrated in China, bismuth faces limitations in global availability despite its high potential for substitution. However, China's hegemony in bismuth resources places it in a position to influence both environmental stewardship and steel production in the future [7].

1.3. State of the Art of Free Cutting Steels

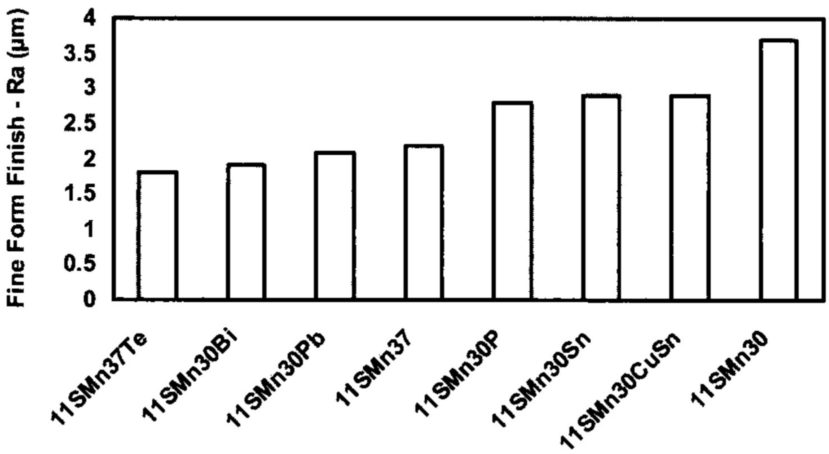
Over recent years, extensive research has been conducted to enhance the machinability of this steel, with a simultaneous exploration of lead alternatives. Much of this research is driven by the impending extension of the EU Directive on End of Life Vehicles across additional sectors, which was reviewed for the last time in 2023. This directive, initially established on September 18, 2000, restricts now the utilization of lead in steel manufacturing processes to a maximum of 0.1% by weight as an alloying element [8]. Researches are now trying to find solutions that provides similar, if not better, performances and affordable prices. Therefore many alloying material are usually taken into consideration when looking for alternatives. The well known 11SMn30 and 11SMn30Pb have been taken as a model and modified into different steels. The most studied are the followings:

- 11SMn30,
- 11SMn30Bi,
- 11SMn37,
- 11SMn30Sn,
- 11SMn30CuSn.

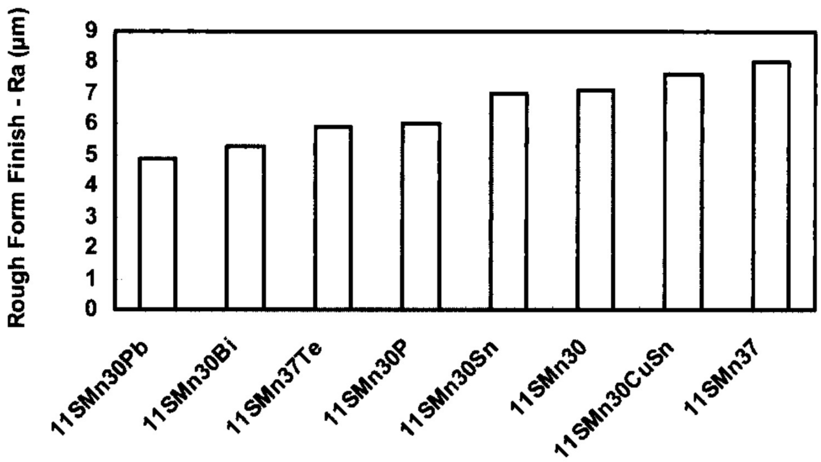
Many studies use 11SMn30Pb as a benchmark for comparison, as it is one of the most widely used free-cutting steels on the market. Among the newly researched alloying materials, leaded steel has demonstrated superior performance in tests with high-speed steel tools and lubricants, excelling in production rate, surface finish, and chip formation. When tested with coated carbide tools across various cutting speeds, the standard non-leaded 11SMn30 steel exhibited good tool wear characteristics but produced poorer chip forms compared to leaded steel. Steels with increased sulfur content showed enhanced performance relative to 11SMn30 steel in high-speed steel tool and lubricant tests but did not match the production rate of leaded steel. Additionally, steels containing tin generally did not outperform 11SMn30 steel. However, 11SMn30Bi steel provided performance close to that of Leaded steel in tests with high-speed steel tools and lubricants [9, 10].

In particular, bismuth-added steels exhibit tool life and mechanical properties comparable to those of leaded steels, while requiring only half the amount of additional material. Additionally, bismuth-added steels offer superior chip disposability and cold forgeability compared to leaded steels. The enhanced machinability of bismuth-added steels is primarily due to the improved liquid metal embrittlement effect of bismuth, which is explained by its higher wetting capability with the steel matrix [9].

In tests conducted at relatively low cutting speeds ($V_c < 100\,\mathrm{m/min}$) with high-speed steel tools and lubricants, the leaded steel grade (11SMn30Pb) demonstrated superior performance in production rate, chip form and surface finish, as it can be seen in Figure 1.3. This improvement is attributed to reduced friction with the tool and enhanced chip breakage when using leaded steel. Additions of lead (and bismuth) also result in a smaller and more stable built-up edge on the tool across a wide range of cutting conditions, further enhancing surface finish. In contrast, the standard non-leaded 11SMn30 steel exhibited poorer performance in these tests at cutting speeds of 100 m/min and below, with a potential reduction in production rate of up to 35% and a poorer surface finish [10].



(a) Fine form surface finish in component production tests [10]



(b) Rough form surface finish in component production tests [10]

Figure 1.3: Surface finish in component production tests

In tests using coated carbide tools across a range of cutting speeds with and without coolant, where built-up edge formation is less significant, the non-leaded steel performed well in terms of tool wear. However, at higher cutting speeds (200 m/min and above), the leaded steel experienced increased tool wear, although all tool wear rates remained low. Despite this, the non-leaded steel showed poorer chip form and, under certain conditions, a poorer surface finish. While switching to non-leaded steel could result in a slight reduction in material costs, this must be weighed against the increased machining costs associated with using high-speed steel tools [9].

The steel with increased sulfur content (11SMn37) showed slightly better performance than the 11SMn30 steel in component production tests using high-speed steel tools and lubricants. It also exhibited good chip formation but did not match the leaded steel in terms of minimum cycle time and surface finish.

Regarding production rate and surface finish, the 11SMn30Bi steel, which incorporates soft bismuth particles akin to the lead particles in leaded steel, demonstrated performance close to that of leaded steel in tests utilizing high-speed steel tools and lubricants. While bismuth is considered a potential technical substitute for lead, its addition does incur higher costs. The hot workability of bismuth steels is reduced, thus the bismuth content is typically limited to below 0.1%, potentially resulting in higher yield losses compared to leaded steel. Furthermore, global bismuth reserves are generally found in conjunction with lead deposits, though some are linked with other minerals such as tungsten and copper-gold ores. Since bismuth is primarily a by-product of other metal extractions, the metals industry cannot significantly boost bismuth production, and substituting large quantities of leaded steel with bismuth-treated steels would likely drive up the market price of bismuth [10].

It has also been shown that as the bismuth content in steel increases, there is a corresponding rise in the amount of bismuth that adheres to or encapsulates sulfides. This leads to a reduction in the average equivalent diameter of sulfides, resulting in smaller sulfide sizes overall. Scanning Electron Microscopy (SEM) reveals that bismuth manifests in free-cutting steel predominantly in three forms: as isolated bismuth within the steel matrix, as a bismuth-coated sulfide (MnS+Bi composite phase), and as bismuth adhering to sulfide. Furthermore, a higher bismuth content is associated with an increased number of composite inclusions. Electrolytic corrosion studies categorize bismuth in steel into three main shapes: spindle-shaped, irregular, and approximately spherical. Sulfides are primarily observed in two forms: type I, which is spherical, and type II, which is rod-like or dendritic [11].

Another extensive research that will be taken into consideration also experimentally to compare it is the Machinability Enhancement of non-leaded Free Cutting Steels, developed by Aachen University [3]. This extensive research also focuses on comparing different alloying elements for Free Cutting Steels, given the necessity to find a substitution for lead. It defines as well machinability criteria and takes 11SMnPb30 as standard reference.

This research focuses on dry and wet turning experiments with both coated and non coated cemented carbide tools, plus an extensive test for auto lathe on a multi splindle turning center.

The results are investigated through key performance indicators that were examined: process forces, surface quality, chip formation, and tool wear.

Process Forces:
Significant reductions in process forces were noted at low cutting speeds across different alloyed free cutting steels. Leaded steel (11SMnPb30) demonstrated a neat advantage at lower speeds, showcasing lower cutting forces compared to non-leaded alternatives. As cutting speeds increased, the differences in forces between leaded and non-leaded materials decreased, with most materials exhibiting similar forces except for those containing Tin (Sn), which consistently showed higher value of forces. Transition speeds for non-leaded materials shifted towards lower values, indicating that they required lower speeds to achieve similar cutting performance. Specific cutting forces (k_c 1.1) remained comparable across all materials, although 11SMnPb30 showed a visible advantage when using coated inserts. The dependence of specific cutting forces on cutting speed was evident, with higher forces recorded for cutting with coated tools due to the larger cutting edge radius.

Surface Quality:
Surface quality was significantly influenced by tool material, cutting speed, feed rate, and workpiece material. The leaded steel 11SMnPb30 produced the best surface finish when HW-P10 tools were used, while the best non-leaded alternative was 11SMn30+Bi. Higher cutting speeds and coated tools positively impacted surface quality by reducing the formation of built-up edges (BUE). The use of coated tools and higher speeds significantly decreased BUE formation, which otherwise degraded surface quality. However, the superior performance of leaded steel diminished when coated tools were used, indicating that the benefits of lead were less pronounced with advanced tooling.

Chip Formation:
The behaviour of the examined materials during chip formation differed significantly. With consistent and controlled chip breakage, the leaded steel 11SMnPb30 and the bismuth-added steel 11SMn30+Bi showed the best chip forms. On the other hand, 11SMn30+Sn created long, continuous chips that were challenging to handle and caused serious chip breaking issues. The most important factor in improving chip fracture was found to be feed rate, where higher feed rates led to better chip breakage. Furthermore, the geometry of the tool was found to have a significant impact on the formation of chips,

with certain geometries having a greater ability to fracture chips.

Tool Wear:
The two factors that affected tool wear patterns the most were cutting speed and tool coating. The deciding factor was slight flank wear at a cutting speed of 100 m/min. Under dry cutting conditions, leaded steels (11SMnPb30) and non-leaded steel 11SMn37 exhibited better behavior at low speeds, sustaining reduced wear rates. Tool wear patterns changed toward major flank wear as cutting speeds reached 200 m/min, and tool life significantly decreased. With regard to 11SMn30+Sn, which showed the highest wear rates, this was particularly evident. When chemical vapor deposition (CVD) coatings were introduced, tool life was significantly increased and, in comparison to uncoated tools, output per cutting insert increased. However because of the higher heat load and the consequent shorter tool life, the use of emulsions significantly decreased tool life, especially for HW-P10 tools.

Deformation Zones and Material Behavior:
By looking at the primary (PDZ), secondary (SDZ), and tertiary (TDZ) deformation zones in cutting processes, the machinability results were further clarified. MnS inclusions created voids in the main deformation zone, lowering specific cutting forces by reducing flow stress. The actions of lead, which reduced flow stress by promoting void formation, stress concentration, and fracture initiation, were most advantageous at low speeds and temperatures. But because bismuth is less concentrated than lead, its advantages were less obvious. The creation of BUE caused forces to rise with increasing cutting speeds, and greater temperatures in the PDZ subsequently reduced flow stress and process forces.

In the SDZ, the formation of friction-reducing build-up layers (BUL) was observed at low cutting speeds. These layers, consisting of smeared MnS and lead inclusions, improved tribological conditions by effectively separating the chip and tool, thereby reducing tangential forces. At higher speeds, increased chip velocity hindered the formation of these layers, resulting in higher friction and reduced effectiveness of lead inclusions. The geometry of the cutting tool also influenced BUL formation, with positive rake angles promoting the removal of MnS layers and negative rake angles supporting their adherence to the tool rake.

1.4. Lead: environmental and health concerns

The presence of lead in steel poses significant environmental and health risks, prompting increased regulatory scrutiny and restrictions, particularly within the European Union (EU). This trend towards minimizing and eventually eliminating lead in steel is expected to intensify due to a combination of stringent EU norms, evolving technological capabilities, and growing societal awareness of the dangers associated with lead exposure.

The European Union has established rigorous environmental and health standards aimed at reducing hazardous substances in industrial materials, driven by directives such as the Restriction of Hazardous Substances (RoHS) Directive and the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) Regulation. These frameworks aim to limit the use of substances that pose significant risks to human health and the environment. Lead is classified as a substance of very high concern (SVHC) under REACH due to its toxicity and persistence in the environment. Consequently, manufacturers within the EU are increasingly pressured to find safer alternatives and comply with these regulations to avoid penalties and ensure market access.

The shift away from lead in steel is also driven by increasing societal awareness and demand for environmentally responsible and health conscious products. Consumers and industries alike are prioritizing sustainability and the reduction of hazardous substances in their materials and products. This cultural shift is reflected in corporate social responsibility (CSR) initiatives and the adoption of green manufacturing practices, which often exceed regulatory requirements. Companies that proactively eliminate lead from their products can enhance their market competitiveness, appeal to eco-conscious consumers, and mitigate potential future liabilities associated with lead contamination.

Moreover, the potential health impacts of lead exposure are well-documented, including neurological damage, developmental issues in children, and various chronic diseases. The EU's commitment to public health protection underpins its rigorous approach to restricting hazardous substances. By phasing out lead in steel, the EU aims to safeguard its population from the insidious effects of lead exposure, which can occur through various pathways including air, water, and soil contamination resulting from industrial processes.

1.5. Thesis objective

The purpose of this thesis is to characterize three different types of steel: 11SMn30, 11SMnPb30, and 11SMnBi30. The first two types are already commercially available and widely utilized in various industries, while the third type, due to its higher cost, has not yet been fully integrated into the market.

Initially, these steels will undergo comprehensive mechanical testing, which will include tensile tests, Charpy impact tests, Vickers hardness tests, and inclusion analysis. Following this mechanical characterization, the steel bars will be subjected to turning tests at high cutting speeds of V_c=300 m/min to V_c=350 m/min. During these tests, several key parameters will be measured and/or evaluated, including reaction forces, surface roughness, and chip formation. These parameters, along with other minor ones, will be used to compare the performance of the three steels under high-speed conditions to determine which steel exhibits superior performance.